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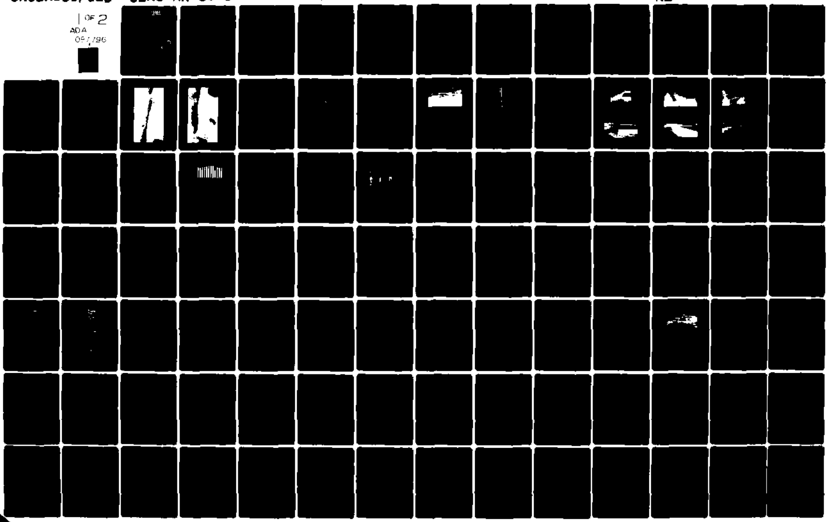

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MR 80-3

Beach and Inlet Changes at Ludlam Beach, New Jersey

by

Craig H. Everts, Allan E. DeWall, and Martin T. Czerniak

MISCELLANEOUS REPORT NO. 80-3

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Beach profile surveys	Ludlam Beach, N.J.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

[illegible] surveys of the above MSL beach were made along 20 profile loca- [illegible] Beach, New Jersey, from 1962 to 1972. The surveys provided [illegible] and partial beach volume change and shoreline position. Storm [illegible] variable, with adjacent profiles often showing opposite [illegible] loss [illegible] MSL, resulting from seven storms, aver- [illegible] per foot [illegible] yards per storm. For three of the [illegible] shoreline position suggested accretion

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) while the beaches actually suffered a volumetric loss. Clear seasonal trends in the volume of sand above MSL were evident. A net accretion occurred from June through October, while November through May was a period of sand loss. The average seasonal range in sand volume above MSL was 18 cubic yards per foot. The seasonal range of sand volume change within the Sea Isle City groin system, located in the middle of the study area, averaged less than 10 cubic yards per foot. Yearly changes in sand volume varied from a gain of 2.9 cubic yards per foot to a loss of 4.6 cubic yards per foot. Net yearly sand volume changes over the 10-year survey interval averaged -1.12 cubic yards per foot per year (a loss of 40,000 cubic yards per year from the entire island above MSL). The average MSL shoreline retreat rate for the same interval was 8.2 feet per year. The inlets bounding Ludlam Beach are characterized by an erratic shoreline, submarine bars, and shoal movements which typify inlets along sandy coasts. Corson Inlet, on the north, widened and migrated south at an average rate of 92 feet per year over the study period. Townsend Inlet migrated southward at an average rate of 9 feet per year. The inlets remove sand from the littoral zone at the expense of downdrift beaches. Thus material is released gradually or abruptly, such as following the March 1962 storm. A sand wave initiated by this unique event contained about 240,000 cubic yards of material which was moved from Corson Inlet southward at an average rate of 5 feet per day. Passage of the sand wave resulted in a time-ordered sequence from north to south of a sand volume gain followed by a volume loss on the beach profiles. Periods of shoreline advance alternated with periods of shoreline retreat. Groins at Sea Isle City appear to have their greatest effect on the downdrift coast by deflecting north to south littoral drift offshore. This seaward deflection results in a downdrift "shadow zone" where less than the normal amount of sediment moved offshore is returned.

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PREFACE

This report is one of a series describing the results of the U.S. Army Coastal Engineering Research Center (CERC) Beach Evaluation Program (BEP). One aspect of the program, and the subject of this report, is to provide basic engineering information on changes in the volume of sand on beaches above mean sea level, and on changes in shoreline position, as obtained from long-term beach survey projects. The work was carried out under the CERC coastal process research program.

Craig H. Everts, Chief, Engineering Geology Branch, prepared the report with the assistance of Allan E. DeWall and Martin T. Czerniak, under the general supervision of C.J. Galvin, former Chief of Coastal Processes Branch, CERC.

Over the 10-year study interval, principal investigators were J.M. Darling, C.J. Galvin, C.H. Everts, and A.E. DeWall. The U.S. Army Engineer District, Philadelphia, performed all survey work except for a period in 1963 and 1964 when it was contracted to Mauzy, Morrow & Associates of Lakewood, New Jersey. Visual wave data were provided by H. Wright of Sea Isle City. An analysis of 20 sequential sets of vertical aerial photos was made for the Philadelphia District in conjunction with another study on Ludlam Beach. The results of that study are included in this report.

L.M. Atkinson, C. Jones, J. Moore, D. Fresch, E.A. Kohler, W.Y. Der, C.F. Thomas, and J.L. Miller assisted in data reduction. M.V. Fleming, T.J. Lawler, J. Buchanan, L.M. Atkinson, W.N. Seelig, D. Mowrey, and B. Sims were responsible for computer programing. P. Pritchett processed and analyzed much of the visual wave data. D.C. Wilson assisted in the aerial photo analysis.

Comments on this publication are invited.

Approved for publication in accordance with Public Law 166, 79th Congress, approved 31 July 1945, as supplemented by Public Law 172, 88th Congress, approved 7 November 1963.

Ted E. Bishop

TED E. BISHOP
Colonel, Corps of Engineers
Commander and Director

TABLES

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FIGURES--Continued

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FIGURES--Continued

CONTENTS

FIGURES--Continued

CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	by	To obtain
inches	25.4	millimeters
	2.54	centimeters
square inches	6.452	square centimeters
cubic inches	16.39	cubic centimeters
feet	30.48	centimeters
	0.3048	meters
square feet	0.0929	square meters
cubic feet	0.0283	cubic meters
yards	0.9144	meters
square yards	0.836	square meters
cubic yards	0.7646	cubic meters
miles	1.6093	kilometers
square miles	259.0	hectares
knots	1.852	kilometers per hour
acres	0.4047	hectares
foot-pounds	1.3558	newton meters
millibars	1.0197×10^{-3}	kilograms per square centimeter
ounces	28.35	grams
pounds	453.6	grams
	0.4536	kilograms
ton, long	1.0160	metric tons
ton, short	0.9072	metric tons
degrees (angle)	0.01745	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins[1]

[1]To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use formula: C = (5/9) (F -32).

To obtain Kelvin (K) readings, use formula: K = (5/9) (F -32) + 273.15.

SYMBOLS AND DEFINITIONS

i consecutive number of a given survey in month or year

N total number of surveys in month or year

p profile line (No.)

t date of survey

t_m month of interest

t_o date of reference survey being used to measure change

t_y year of interest

x_1 landward bound

x_2 MSL intercept

y elevation above MSL

Δs unit length of beach front

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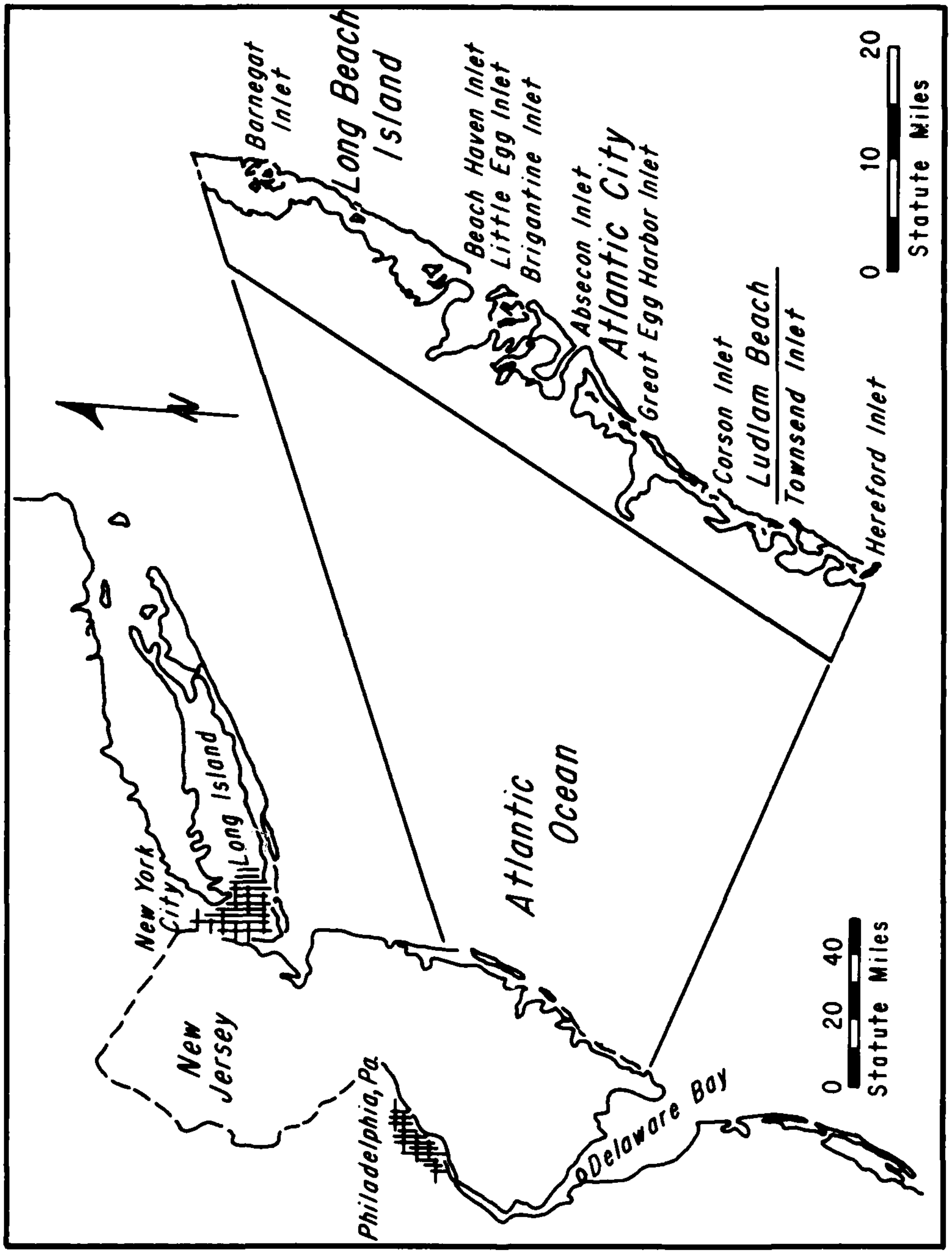

Figure 1. Ludlam Beach, New Jersey.

BEACH AND INLET CHANGES AT LUDLAM BEACH, NEW JERSEY

by
Craig H. Everts,
Allan E. DeWall, and
Martin T. Czerniak

I. INTRODUCTION

This report presents the results from a 10-year study of 20 profile lines at Ludlam Beach, New Jersey, between October 1962 and March 1972. About 90 surveys were made along each profile line from landward of the dunes, or from a bulkhead, to wading depth in the surf zone. Additional data on Ludlam Beach were obtained from aerial photos, visual wave observations, sand samples, personal inspections, and previous reports.

Ludlam Beach is one of 16 beaches on the U.S. Atlantic coast under study in the Coastal Engineering Research Center's (CERC) Beach Evaluation Program (BEP). The objective of the program is to observe topographic changes on beaches in response to waves and tides of specific intensity and duration as a first step in developing a storm warning system for low-lying coastal communities. The BEP was a direct outcome of investigations into the effects of the Great East Coast Storm of March 1962 (see U.S. Congress, 1962).

Although this report meets the objective of the BEP, it primarily provides basic engineering information for use in the planning and design of protective structures, or of remedial measures, for stabilizing and maintaining beaches. Changes in the shape, sand volume, and shoreline position of the beach above mean sea level (MSL) elevation are described for the entire length of the barrier island. The duration of the study and the number of surveys (1,760) make it unique in that several frequencies of beach change, such as those associated with storms, between months, years, and over the 10-year study period, are identified. In addition, using less accurate data from an analysis of 20 sequential sets of vertical aerial photos, longer term (1949-74) changes in the position of the shoreline are available. The report also describes shoreline changes at the inlets bounding Ludlam Beach. Information is thus provided on where, when, and how much beach material is eroded or deposited, and in what direction it is transported. Definitions of the terms used in the analysis of beach changes are given in Appendix A.

II. LUDLAM BEACH LOCALITY

1. Physical Setting.

Ludlam Beach, one of a series of elongated barrier islands along the Atlantic coastline of southern New Jersey, is located about 100 miles south of New York City and 20 miles south of Atlantic City (Fig. 1). The region landward of Ludlam Beach is characterized by large bays, marshes, and lagoons connected to the Atlantic Ocean by tidal inlets (Figs. 2 and 3).

Ludlam Beach is bounded on the north by Corson Inlet and on the south by Townsend Inlet (Fig. 3). These inlets are navigable for small craft, and connect to the New Jersey Intracoastal Waterway channel west of the island. The waterway passes through Ludlam Bay which is a 0.75- by 1.5-mile-wide shallow-water body behind the island, midway between Corson and Townsend Inlets.

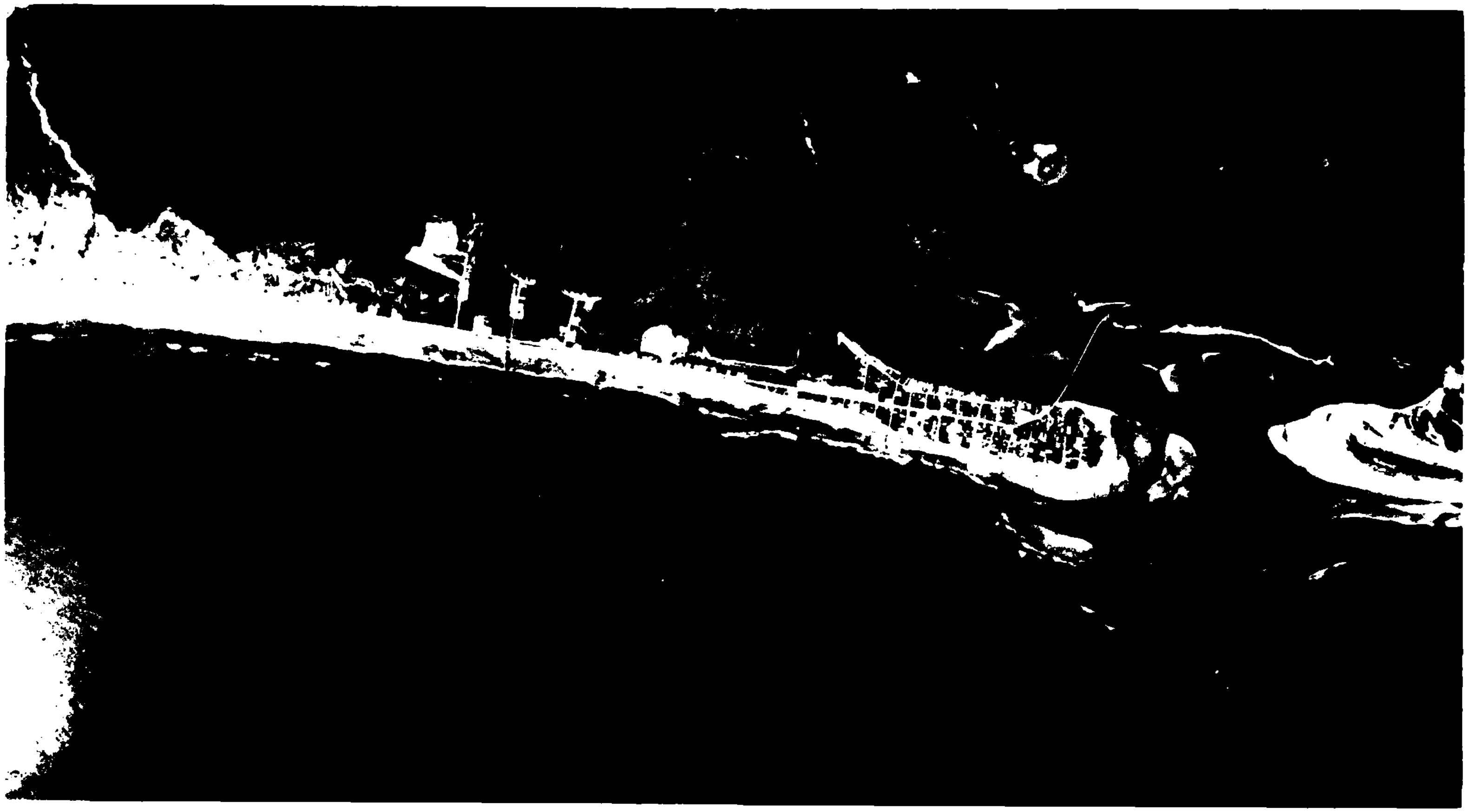

Figure 2. Photo mosaic of Ludlam Beach, 30 April 1973 (photo courtesy of National Aeronautics and Space Administration).

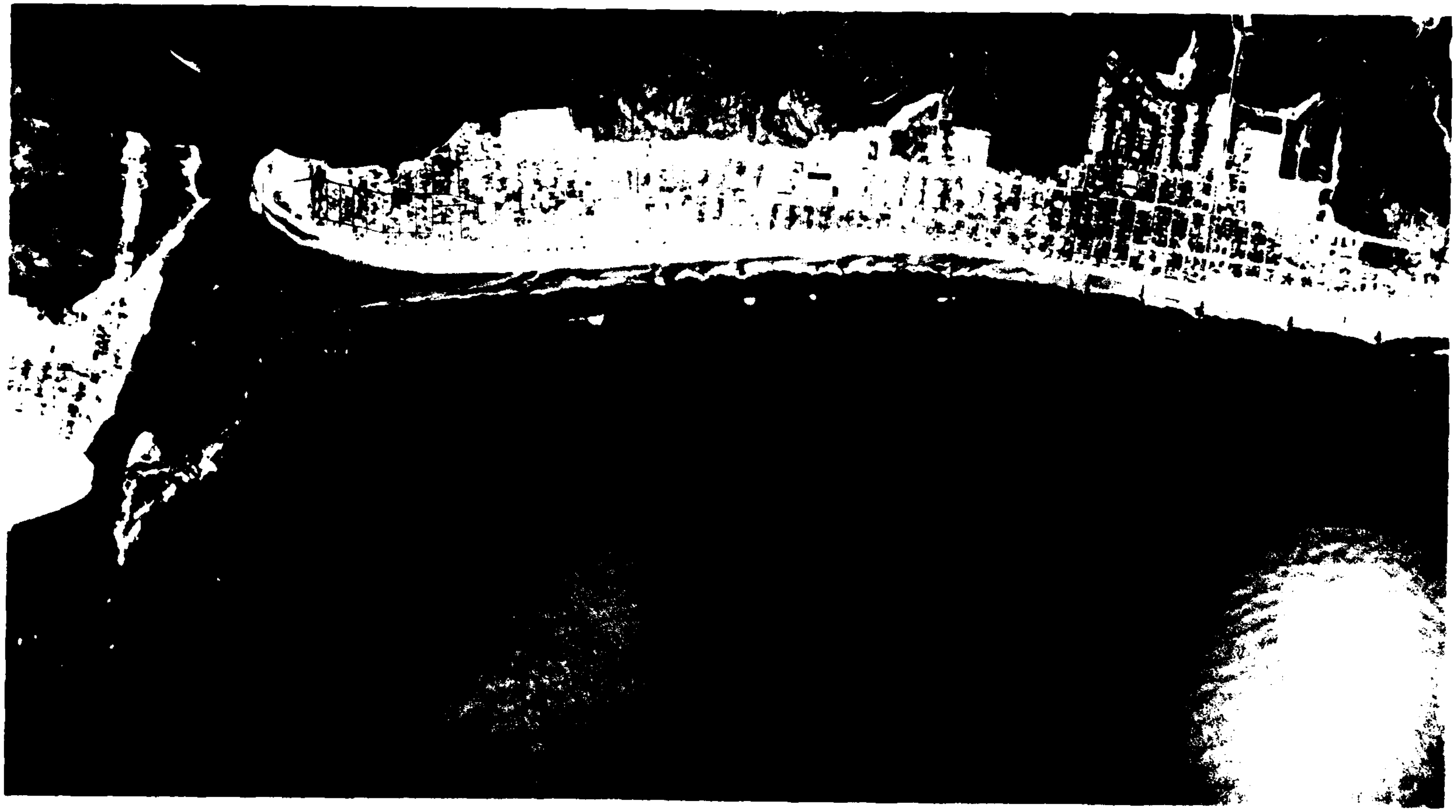

Figure 2. Photo mosaic of Ludlam Beach, 30 April 1973 (photo courtesy of National Aeronautics and Space Administration).--Continued

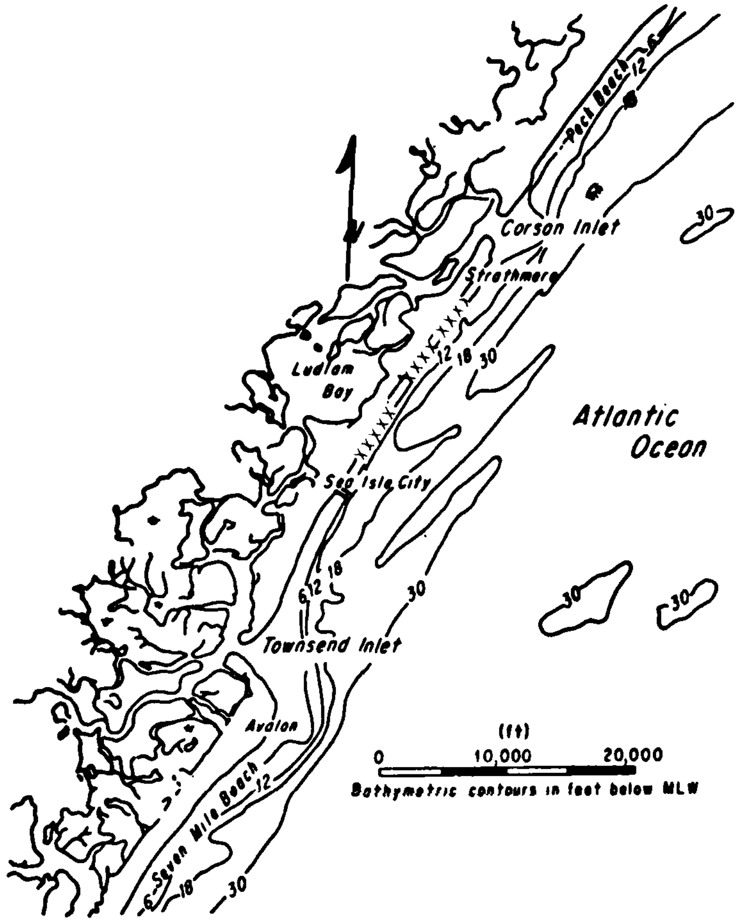

Figure 3. Ludlam Beach showing the barrier island backed by a 2- to 3-mile-wide tidal marsh. Note the 5,000-foot-seaward offset of the island south of Townsend Inlet relative to Ludlam Beach. Crosshatch shows locations of peat-marsh material exposed on the beach on 8 March 1962 (from National Ocean Survey chart 1217).

Ludlam Beach is 7.5 miles long and 0.25 to 1 mile wide. The higher elevations and most of the inhabited area are along the oceanside of the island. Coastal dunes average 8 to 15 feet in elevation above MSL. On the landward side, the island is largely intertidal marsh dissected by drainage ditches, although recent development has extended into this area along the southern half of the island. The location of the surveyed profile lines at Ludlam Beach is shown in Figure 4.

2. Coastal Exposure and Bathymetry.

The island centerline of Ludlam Beach is offset 800 feet seaward from the barrier island to the north of Corson Inlet and 5,000 feet landward from the barrier island to the south of Townsend Inlet (Fig. 3). Since Ludlam Beach faces the southeast (N. 30° E.), it is fairly sheltered from westerly flow, especially from strong wave-generating northwest winds (Fig. 1). It is partially sheltered from northeast winds by the protrusion of the New Jersey coast

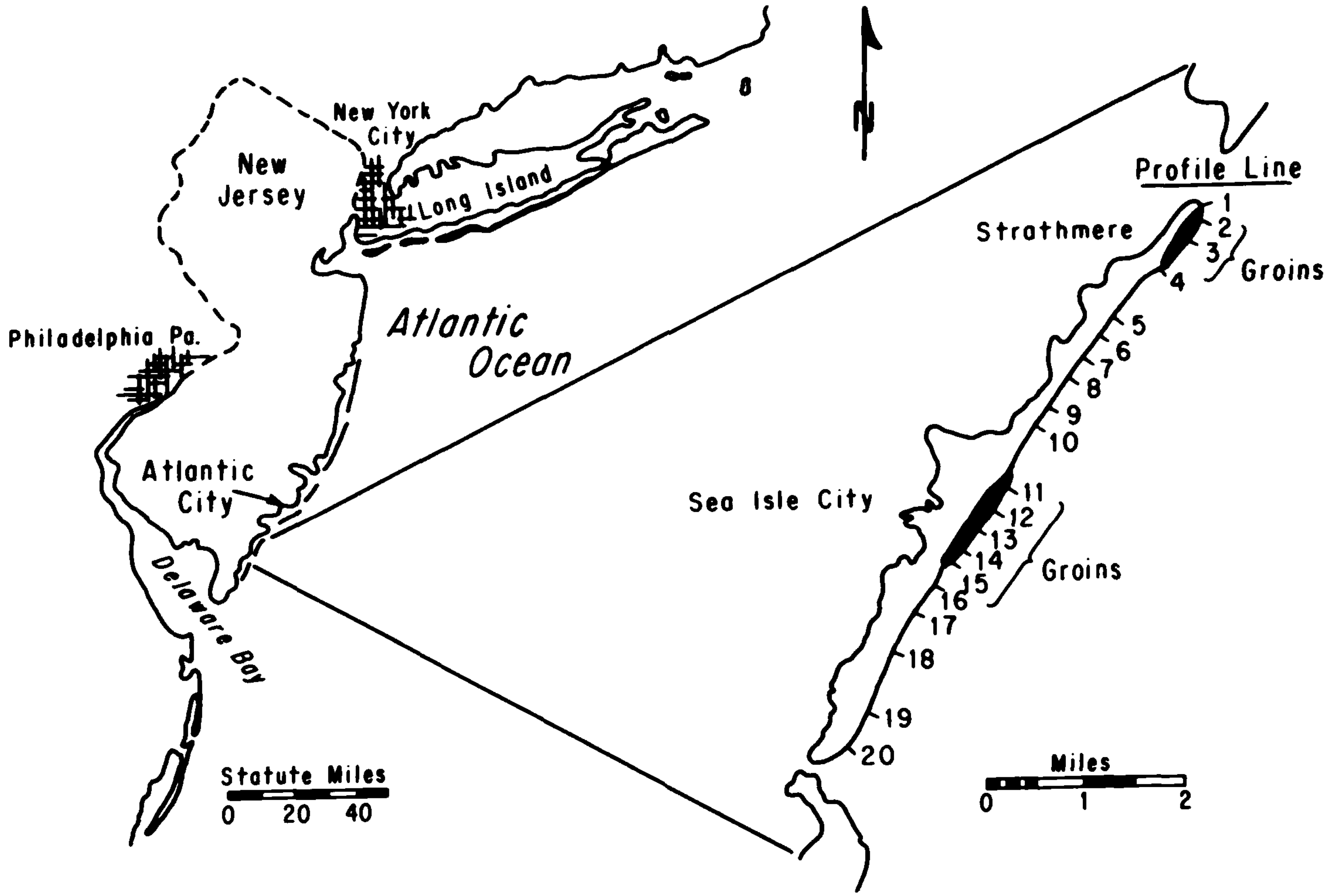

Figure 4. Location of profile lines, Ludlam Beach, New Jersey. Profile lines were surveyed from landward of the extreme high water line to below MSL.

to the north and, to some extent, by Long Island and the shoals south of Cape Cod. However, the waves generated by northeast winds are the dominant cause of changes on the beach (U.S. Army Engineer District, Philadelphia, 1966).

There are three scales of bathymetry affecting the wave climate of Ludlam Beach: a relatively flat continental shelf, an offshore shoal area where the Inner Continental Shelf rises to meet the beach, and an inner shoal area visible on aerial photos at low tide. Based on analyses of data from an Atlantic City wave gage 20 miles to the north, a typical wave in this region has a period of 8 seconds. This means that the 30-fathom contour is the approximate limit where such a wave begins to be modified by the bottom (from linear wave theory). The nearest point of the 30-fathom contour to Ludlam Beach is 60 miles offshore, and for most of that 60 miles, the bottom slopes upward to the shore at less than 2 feet per mile (Everts, 1978).

Within a few miles of the shore, there is a prominent ridge trending N. 50° E.; i.e., a 20° angle with the trend of Ludlam Beach with the angle opening to the north. This ridge appears to be what was called a linear shoal in Duane, et al. (1972). The landward continuation of the ridge intersects the southern part of Ludlam Beach (Fig. 3). The ridge is well marked by the -30-foot contour.

Submarine bars are visible on many aerial photos of the littoral zone along the island (see Fig. 2). These bars make a slight angle with the shore, but the angle usually opens to the south rather than to the north as does the submarine ridge marked by the -30-foot contour. A more detailed discussion of these bars is given later in this report. The same aerial photos show large sand deposits off the mouths of Corson and Townsend Inlets. These deposits affect the bottom out to about the -18-foot contour on hydrographic charts (Fig. 3).

Bottom features are important in their effect on wave height and direction. Computations suggest that bottom dissipation due to wave travel over the Continental Shelf off Ludlam Beach will have little effect on most waves outside a 7-mile radius of the shore. However, bottom dissipation within these last 7 miles can be very large, especially for high storm waves which could lose 50 percent or more in height, according to the predictions of Bretschneider and Reid (1953).

3. Beach Sediment.

Ludlam Beach is composed of fine sand, although outcrops of consolidated peat are usually exposed at low tide within profile lines 4 to 9 and occasionally after storms in profile lines 16, 17, and 18 (Fig. 5). The outcrops are generally 1- to 2-feet-thick planar horizontal beds lying at about MSL elevation. At profile lines 4, 5, and 6, the peat, often containing small stumps, is exposed during much of the fall-winter-spring periods of low sand volume on the beach.

Sand samples were collected at profile lines 4, 10, and 17 from the backshore to slightly below MSL. An analysis of 102 samples collected from January 1968 to March 1969 indicated an average median diameter of 0.23 millimeter (Ramsey and Galvin, 1977). The coarsest sand (0.25 millimeter) was found between midtide and mean low water (MLW) elevations; the finest sand (0.20 millimeter) was obtained on the berm. Samples collected in October, before the fall storms had cut back the beach, averaged 0.19 millimeter in median diameter across the profile. January samples averaged 0.26 millimeter.

Ludlam Beach sand is composed of approximately 95-percent well-rounded quartz (McMaster, 1954). The remainder of the beach sediment is feldspar,

Figure 5. Outcrop of consolidated peat at profile line 16.

broken shells, and heavy minerals, predominantly pink garnet and ilmenite. Much of the sand is reworked beach material, transported to Ludlam Beach from the north (Colony, 1932; Caldwell, 1966). However, in an offshore sediment study near Atlantic City, Frank and Friedman (1973) concluded that the Continental Shelf has been the source of some of the central New Jersey beach material.

4. Civil Works History.

Beach erosion control and rehabilitation measures began on Ludlam Beach as early as 1920. In 1922 the State of New Jersey began a program to assist communities and property owners in the construction of shore protection structures. The Federal Government began participating in beach projects in 1930. Erosion control efforts have included the placement of groins and bulkheads at Sea Isle City and Strathmere. The entire ocean front of the island was rehabilitated following severe storms in 1962 and 1964 (U.S. Army Engineer District, Philadelphia, 1966).

a. Groins. In 1974, Ludlam Beach had 17 groins, some constructed as early as 1920, located in Sea Isle City and in Strathmere. The groin system at Sea Isle City extended from 500 feet north of profile line 11 (30th Street) to 1,000 feet south of profile line 15 (47th Street), a distance of about 6,000 feet (Fig. 4). At Strathmere, the groins extend along the south shore of Corson Inlet, west of profile line 1 to 400 feet north of profile line 4.

The history and characteristics of the Sea Isle City groins are shown in Figure 6 and Table 1. Seven groins, the first to be constructed at Sea Isle City, were completed in 1923. Although deteriorated, they remained until removed in a 1944 hurricane. A single stone groin (No. 3 in Fig. 6) constructed

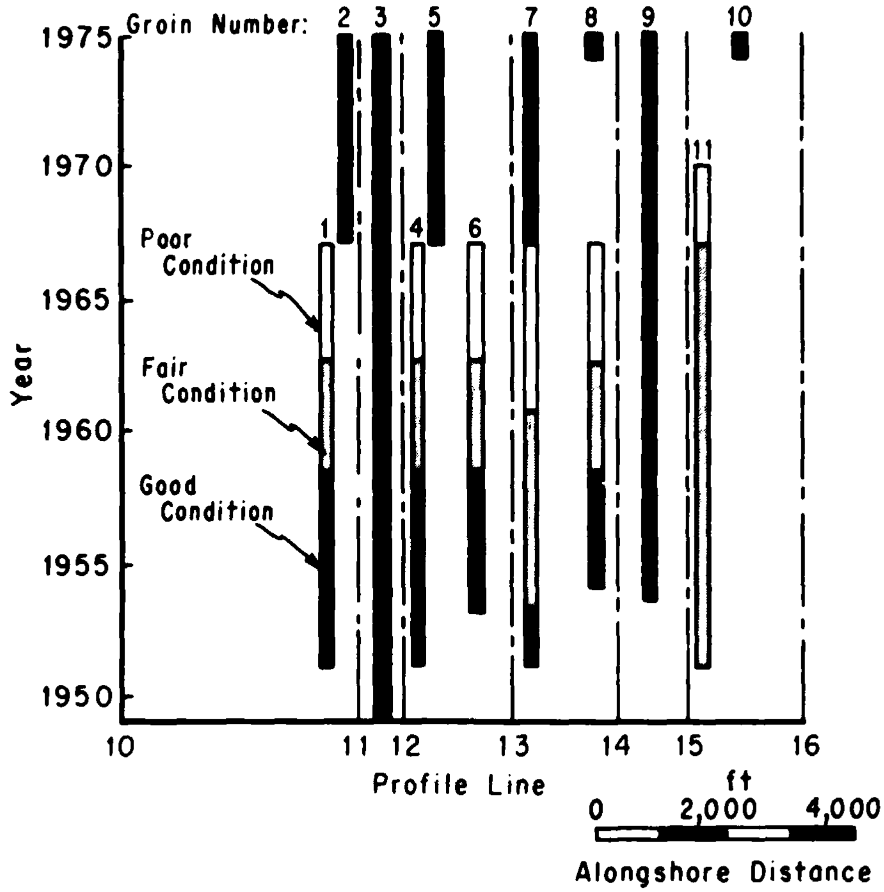

Figure 6. History of groins constructed at Sea Isle City since 1949. Groin number 3 was constructed in 1945.

Table 1. Characteristics of groins at Sea Isle City, New Jersey.

Groin No.	Groin type	Top elevation landward (ft)	Seaward (ft)	Top width (ft)	Length (ft)
1	Timber crib	9	6	8	300
2	Timber and stone	10	2	12 to 14	575
3	Stone	13	9	12 to 14	255
4	Timber crib	11	7	8	375
5	Timber and stone	10	2	12 to 14	580
6	Timber crib	13	7	8	300
7	Timber crib and stone[1]	10	2	12 to 14	610
8	Timber crib and stone[1]	10	2	12 to 14	610
9	Timber crib and stone[1]	9	2	12 to 14	610
10	Timber crib	6.5	6	9	300
11	Timber and stone	10	2	12 to 14	610

[1]Timber crib until 1967, then timber with seaward 280 feet of stone.

in 1945 is the only pre-1950 groin in existence today. An extensive project from 1952 to 1954 added seven new groins (Fig. 5). Further construction in 1967 and 1973 resulted in three new groins and improvements to three (Fig. 7).

In 1920 the municipality of Strathmere constructed five timber groins near Corson Inlet. Since then, the groin field has expanded to 10 groins which were in generally poor condition in 1974. The northernmost groin near Corson Inlet was completely flanked by erosion, and timber groins at the south end of the field were breached (Fig. 8).

b. Bulkheads. An 800-foot-long timber wave breaker, constructed at Strathmere in 1920, remained until 1967 when it was replaced by a 2,650-foot timber bulkhead with rubble armor (Fig. 9). Since then, the south end of the bulkhead has been difficult to maintain. A series of "pigpen" bulkheads constructed in 1920 have failed near profile line 4 (Fig. 10).

At Sea Isle City, a 4,750-foot-long timber wave breaker constructed by the city in 1923 and a 6,075-foot-long bulkhead constructed by property owners between 1945 and 1955, were both destroyed by storms. From 1950 to 1955 the city constructed and maintained 1,920 feet of timber bulkhead and sand fences at 30 street ends which were later destroyed by wave action. A present timber bulkhead with a rubble armor toe, constructed between 1963 and 1967, begins near 29th Street (profile line 11, Fig. 3) and extends to 55th Street (profile line 16, Fig. 11). Behind most of the bulkhead is a paved promenade with a top elevation of 14.8 feet above MLW. The front of the bulkhead between 50th and 55th Streets has experienced continued erosion in recent years (H. Wright, Supervisor of Public Works of Sea Isle City, personal communication, 1974). By February 1974, the beach adjacent to the southern end of the bulkhead had retreated 50 feet landward between 55th and 57th Streets (Fig. 12).

At Townsend Inlet, a low sand dune is the only protective structure along the ocean or inlet front of Ludlam Beach. At Avalon on the south side of the inlet, groins and bulkheads have been constructed to impede the southward migration of the inlet.

c. Beach Fill and Dune Construction. The first recorded artificial beach fill and dune construction on Ludlam Beach occurred after the entire beach front eroded during the March 1962 storm. A total of 905,000 cubic yards of fill was placed along 35,200 feet of ocean frontage between Corson and Townsend Inlets. This material was primarily used for the reconstruction of a dune, built in a Caldwell Section (U.S. Army Engineer District, Philadelphia, 1966) to a top elevation of 12 feet above MLW. A sand fence was placed along the top. Following serious erosion at Strathmere during a September 1964 storm, the dune was rebuilt with a gravel core to a top elevation of 14 feet above MLW. Beaches were not significantly replenished after the 1962 to 1964 fill program (H. Wright, personal communication, 1974).

d. Inlet dredging. Inlet dredging data from 1963 to 1974 are available for both Corson and Townsend Inlets (Table 2). In all cases, sediment was moved from north to south within the inlets using a side-casting dredge.

5. Wind, Wave, and Tide Data.

a. Wind Data. Ludlam Beach is located at approximately 39° N. latitude, which is within the zone of prevailing westerly winds. Occasional strong

Figure 7. Groin in Sea Isle City, February 1974.

Figure 8. Flanked groin at south end of Strathmere, February 1974.

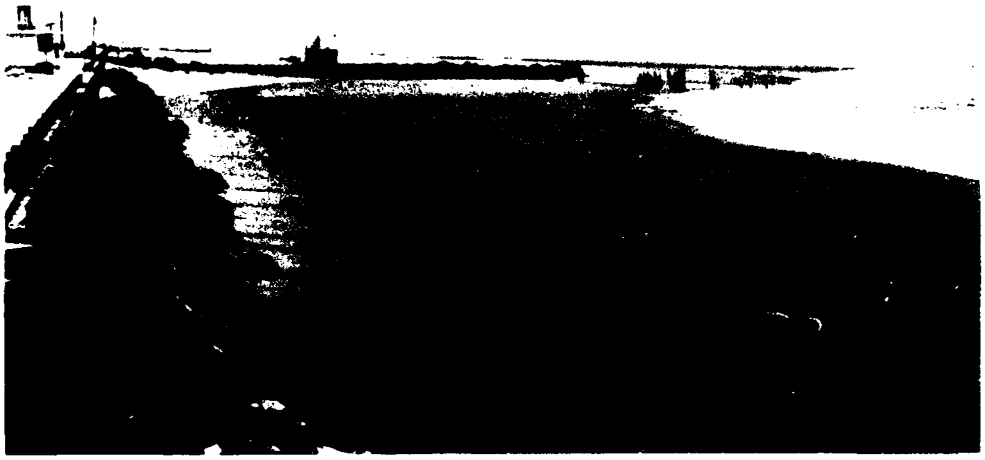

Figure 9. Strathmere bulkhead, view toward profile line 3, February 1974.

Figure 10. "Pigpen" bulkheads at south end of Strathmere, February 1974.

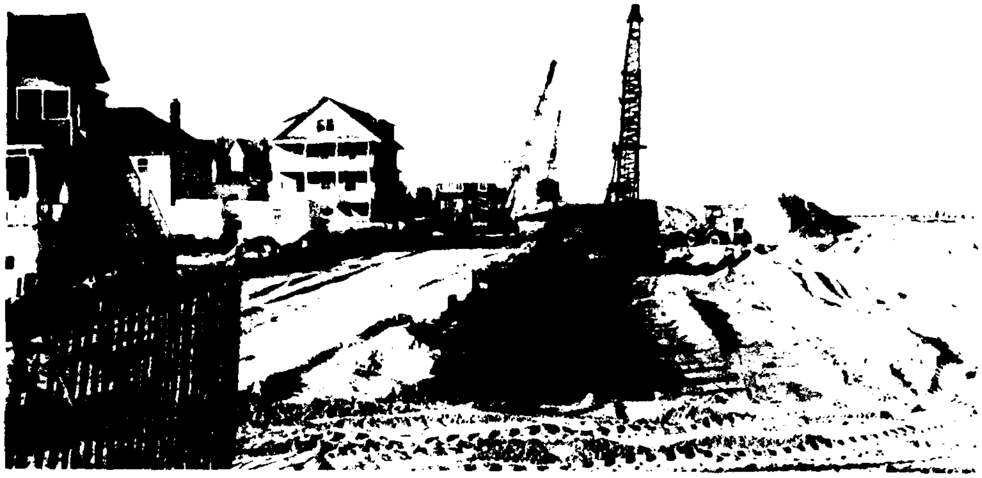

Figure 11. Sea Isle City bulkhead under construction just north of profile line 14, April 1963.

Figure 12. Eroded beach south of bulkhead in Sea Isle City, February 1974.

Table 2. Volumes dredged from Corson Inlet and Townsend Inlet, 1963-74.

Corsen Inlet		Townsend Inlet	
Date	Dredged volume (yd^3)	Date	Dredged volume (yd^3)
1963 to July 1967	0	1963 to June 1967	0
7-22 July 1967	43,680	12-30 June 1967	28,900
5-8 July 1968	5,640	1-7, 23 July 1967	11,290
14-15 May 1969	1,670	5-17 June 1968	14,690
		24 Apr. to 7 May 1969	21,460
		10 May to 4 June 1970	40,160
		31 Mar., 16-19 Apr. 1971	10,420
		15, 17-19, 26, 28, 29-30 July 1972	17,560
		14-30 June 1973	1,726
		27 May to 30 June 1974	12,540
		1-31 July 1974	24,710
1967-69 avg. 17,000 yd^3/yr.		1967-74 avg. 26,200 yd^3/yr.	

northeast winds accompany the passage of low-pressure systems along the coast, and strong northwest winds develop around high-pressure systems, especially in the winter. The westerly flow is interrupted during summer months by weaker winds from the south.

Inferred winds at Ludlam Beach are light to moderate during most of the year and predominantly in an offshore direction. Figure 13 is a plot of wind speed and direction as measured between 1968 and 1972 by the U.S. Weather Bureau at the National Aviation Facilities Experimental Center 10 miles inland of Atlantic City and 25 miles from Sea Isle City. Wind direction is that from which the wind blows, reported in degrees clockwise from the north. The resultant speed is the magnitude of the vector sum of the wind velocities. The average speed is the sum of the recorded windspeeds divided by the number of observations. Windspeeds are highest during the winter months and lowest in late summer. High windspeeds, i.e., those that exceed 28 miles per hour, are predominantly from the northeast (U.S. Army Engineer District, Philadelphia, 1966). These winds are associated with storms and are often accompanied by rain or snow.

[illegible] the most severe storms affecting the Atlantic coast, however, [illegible] which also contribute to the loss of [illegible] hurricane [illegible] 1955 to [illegible]

[illegible]

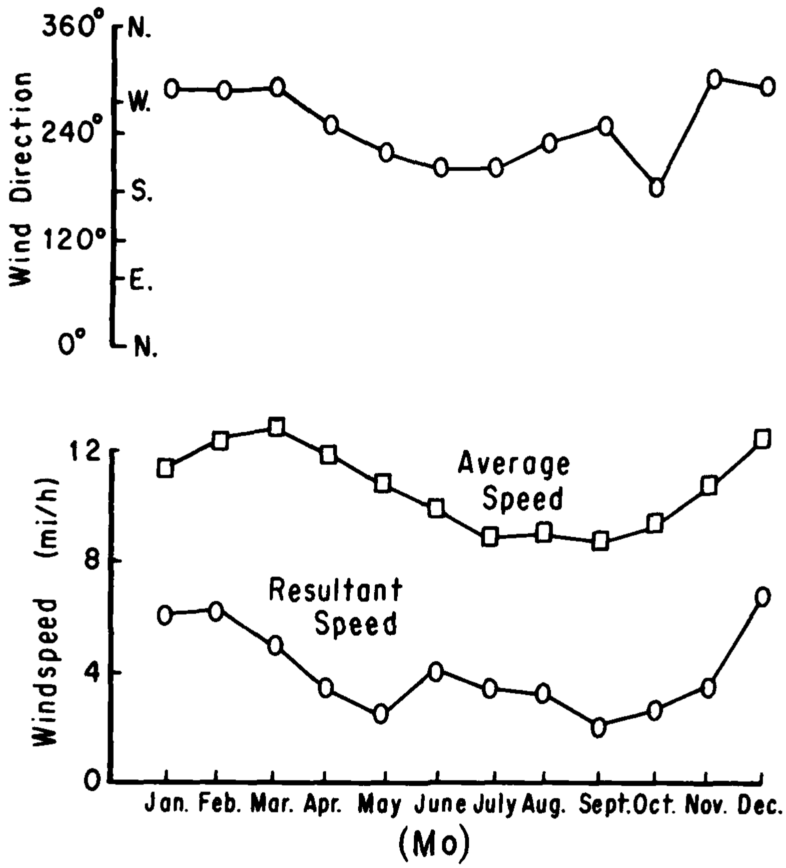

Figure 13. Mean monthly wind speed and direction at Atlantic City, New Jersey (1968-72). Figure illustrates the winter windspeed maximum from the west and northwest.

Table 3. Hurricane and storm data, Atlantic City, 1933-62 (modified from U.S. Army Engineer District, Philadelphia, 1966).

Storm		Minimum distance of center from Atlantic City		Maximum wind		Highest tide
Date	Name	Distance (mi)	Direction	Direction	Velocity[1] (mi/h)	(ft above MSL)
Aug. 1933		125	W.	E.	76	5.0
Nov. 1935[2]		---[3]	---	NE.	66	5.3
Sept. 1936		100	E.	NE.	90	4.7
Sept. 1938		75	E.	W.	72	4.1
Sept. 1944		30	E.	NE.	91(G)	7.6
				N.	82(V)	
Nov. 1950[2]		---	---	E.	72	7.0
Oct. 1953[2]		---	---	N.	29	6.1
Nov. 1953[2]		---	---	NE.	69(G)65(V)	5.0
Aug. 1954	Carol	50	E.	NE.	57	4.4
Sept. 1954	Edna	150	E.	NE.	65	4.6
Oct. 1954	Hazel	125	W.	SE.	80(G)	4.6
				SE.	66	
Aug. 1955	Connie	125	W.	S.	65	4.0
Aug. 1955	Diane	65	N.	SW.	49	3.6
Oct. 1955				E.	60	5.0
Sept. 1956	Flossy			E.	54	4.9
Sept. 1960	Donna	80	E.	WNW.	83(G)	6.1
				WNW.	60	
Mar. 1962[2]		---	---	E.	58(G)	7.2
				E.	44	

[1]Generally fastest mile or highest 1-minute value; (G) denotes gust and (V) 5-minute value.

[2]Not of tropical origin.

[3]Not available.

are caused by hurricanes or extratropical cyclones. The maximum surge elevation at Atlantic City for each year from 1922 to 1968 is shown in Figure 14. A storm surge equivalent to the 1951 surge at Atlantic City could cover 75 percent of Ludlam Island if it occurred at high tide. This is unlikely, however, because for such extensive flooding the foredunes and bulkhead would have to breach. Therefore, the maximum possible coverage is 75 percent.

c. Wave Data. Wave data were obtained between 1957 and 1967 from a CERC staff gage in 18 feet of water on the Steel Pier in Atlantic City, the nearest source of wave gage data. Based on 18,132 observations, Thompson and Harris (1972) determined the mean wave height at Atlantic City to be 2.8 feet. Less than 1 percent of the waves exceeded 8.5 feet (Fig. 15). Figure 16 shows the monthly wave power for waves less than and greater than or equal to 4 feet at Atlantic City, based on an average of 6 years' data (1962-67). Using the mean monthly wave period of 8 seconds obtained from Atlantic City data, a 4-foot wave height results in a wave steepness (wave height/wavelength) of 0.022 at the gage.

The direction of wave approach at the outer breaker zone was observed at near daily intervals near profile line 14 and at irregular intervals near profile lines 5 and 18 (Fig. 3) during the period 1969 to 1974. Distribution of the data is shown in Figure 17. The percent of the total monthly observations is given for one of five possible sectors of wave approach identified in the

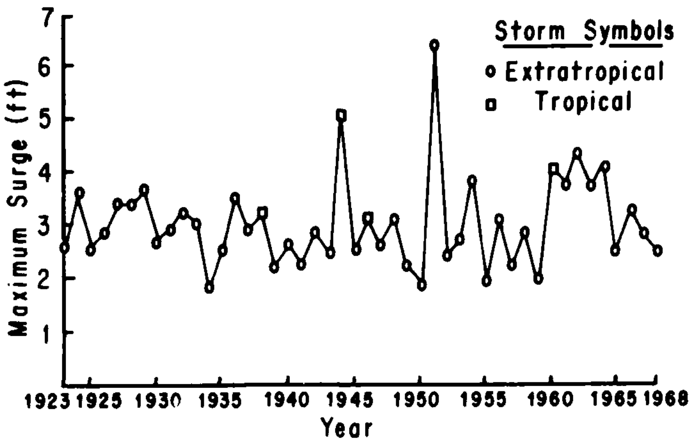

Figure 14. Maximum annual surge at Atlantic City, New Jersey, 1923-68 (from Myers, 1970). The maximum water surface elevation above the predicted astronomical tide is shown. Data were adjusted for the rise in sea level.

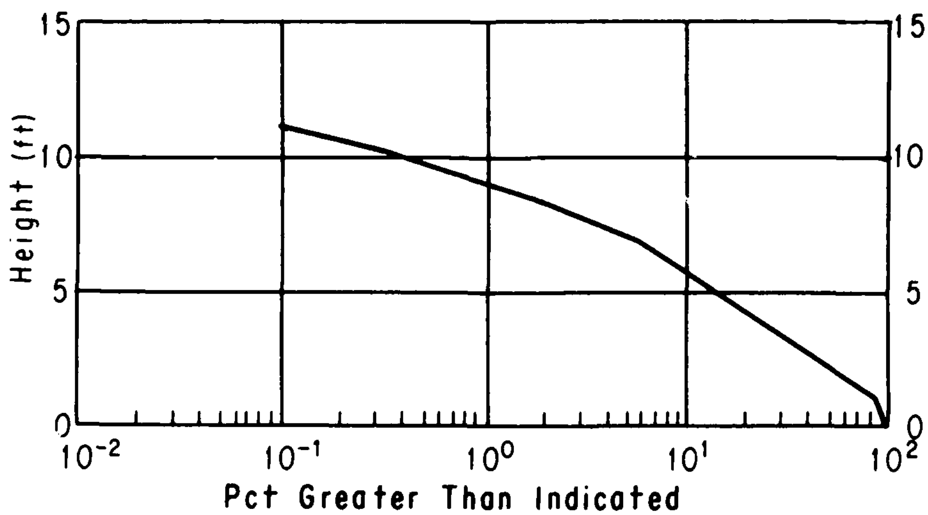

Figure 15. Wave data obtained at Atlantic City, New Jersey, 1957-67 (modified from Thompson and Harris, 1972).

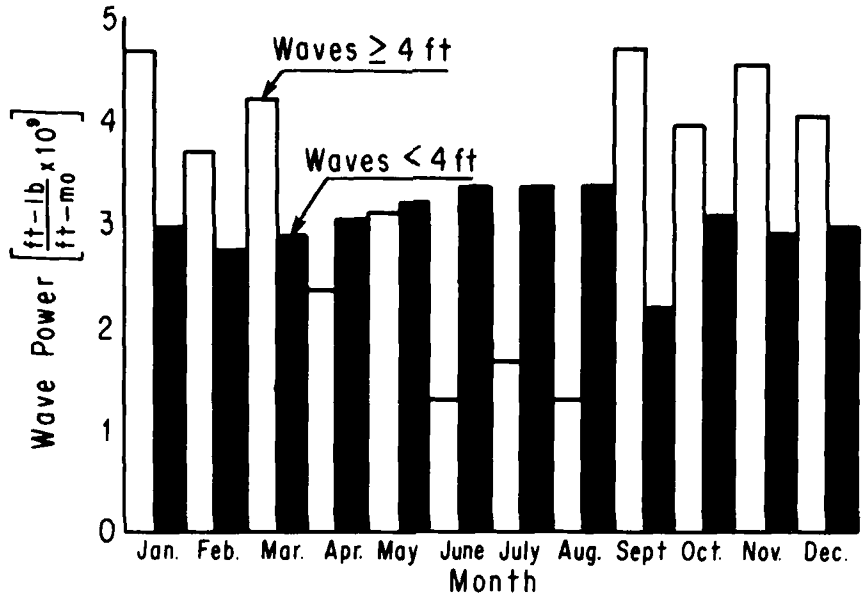

Figure 16. Monthly wave power at Atlantic City, New Jersey, 1962-67.

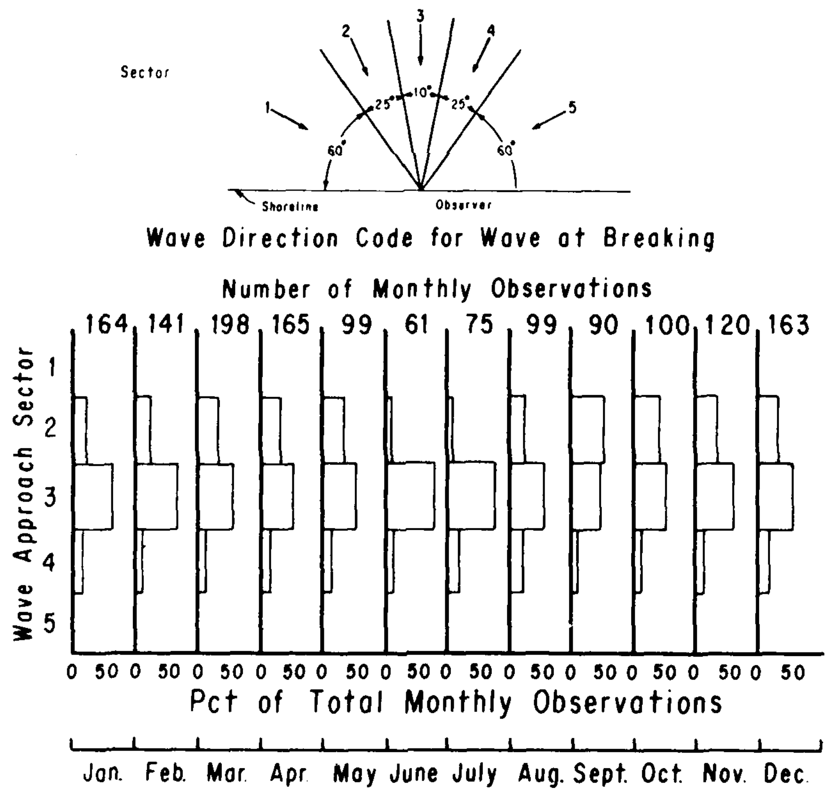

Figure 17. Direction of monthly wave approach at Ludlam Beach, New Jersey, illustrating the tendency of waves to approach from north of the shoreline orientation (island axis orientation equals 030° relative to true north), 1969-74.

upper part of the figure. Waves from sectors 1 or 2, for instance, approach the shore at an angle north of the shore-normal orientation (sector 3).

III. PROCEDURE

The primary data base of this study is beach profiles obtained from 20 profile lines at Ludlam Beach. A series of aerial photos of the area obtained between 1949 and 1974 provides supplementary information.

1. Beach Profiles.

A beach profile is a cross section of the ground surface surveyed at a given time at a profile line. A profile line is identified by one or more fixed points (bench mark and auxiliary mark) across the beach and by a direction. Many beach profiles may be obtained at each profile line.

a. Profile Line Location. The approximate location of the 20 profile lines, numbered from 1 to 20 in a north to south direction, is shown in Figure 4. The spacing between profile lines is tabulated in Table 4; the total distance from profile line 1 to 20 is approximately 35,000 feet (93 percent of the length of Ludlam Beach). Only profile line 1, which faces northeast toward Corson Inlet, is not oriented near-perpendicular to the axis of the island. The surveyors' documentation of the profile lines is given in Appendix B.

Table 4. Profile line spacing at Ludlam Beach.

Profile line	Distance between profile lines (ft)	Profile line	Distance between profile lines (ft)
1		11	3,648
2	720	12	600
3	1,128	13	1,680
4	2,200	14	1,512
5	3,360	15	1,128
6	1,380	16	1,720
7	1,584	17	1,650
8	1,130	18	2,280
9	1,992	19	3,850
10	1,260	20	2,160

Profile lines were usually surveyed from behind the frontal dune or the bulkhead to varying elevations between MSL and 2 feet below MSL. The seaward limit of the profiles was regulated by the tidal stage, wave conditions at the time of the survey, and the maximum wading depth for surveyors. Distance and elevations of each survey are referenced, respectively, to the bench mark on each profile line (App. B) and to the 1929 National Geodetic Vertical Datum.

b. Survey Frequency. Between October 1962 and December 1972, 1,760 profiles were obtained from 90 surveys. The survey frequency varied significantly throughout this period from both year to year and season to season (Fig. 18). Each profile line was surveyed 25 times in 1963, but only 4 times in 1966. Most surveys were made in the fall and winter; relatively few were made in the summer.

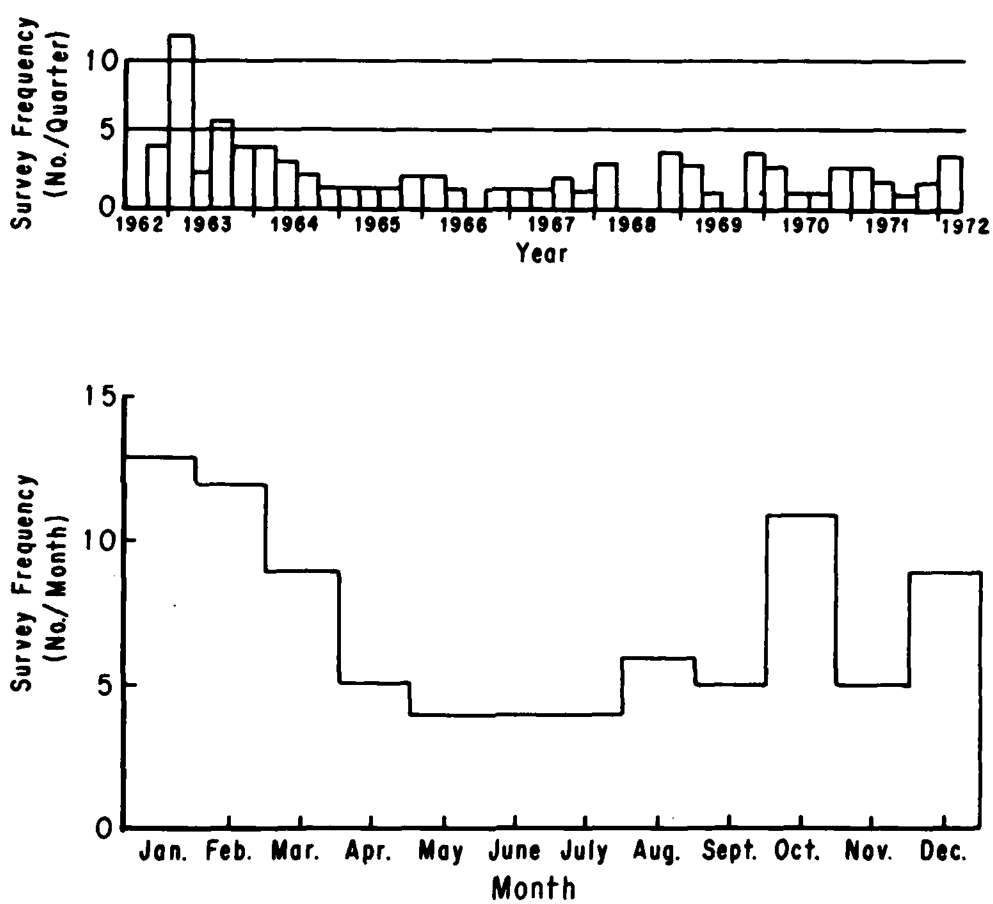

Figure 18. BEP survey frequency, Ludlam Beach, New Jersey.

c. Survey Procedure. Profile lines were surveyed using the transit and stadia method (Fig. 19). The Philadelphia District survey crews performed all survey work except for a period in 1963 and 1964 when it was contracted to Mauzy, Morrow & Associates of Lakewood, New Jersey.

About 15 to 30 minutes was required to survey each profile line, depending on its length and accessibility. Distances (to the nearest foot) and elevations (to the nearest tenth of a foot) were recorded for points every 25 or 50 feet, and at breaks in slope. At the seaward end of the line, measurements were taken by a rodman attempting to wade into the surf zone to the -2-foot MSL elevation (Fig. 20). This attempt was affected by the wave conditions, wind, tidal stage, and temperature. When possible, surveys were done at low tide.

Figure 19. Survey party measuring profile line 14, 16 January 1968.

d. Survey Accuracy, Data Processing, and Quality Control. The accuracy criteria of the profile surveys are 0.1 foot vertical and 1.0 foot horizontal. Since standard survey techniques and equipment were used to collect all data, the random and systematic errors of measurement were under control and did not affect the data. However, the leveling was not closed for each profile survey for any but the 1972 data, and personal errors may be present in the elevation data. Czerniak's (1973) quality control study indicated a 25-percent probability that the elevation of a surveyed point will be recorded in error by ±0.1 foot. Since the probability of multiple occurrences of this rounding error on the same profile is very small, the error, if present, does not adversely affect data analysis.

Beginning in 1968, survey data were recorded in notebooks in the field, then transferred to optical scanning forms and sent to CERC for processing. Prior to 1968, data were also recorded in field notebooks, but surveyors hand-plotted the data on standardized graph paper. At CERC, the survey data were logged and read on an optical scanner (IBM 1232 Optical Mark Page Reader) which converted the data to punchcard format. All pre-1968 plots were digitized (Auto-Trol 3400 digitizer) and placed in the same punchcard format.

The cards were then processed into a Univac 1108 or CDC 6600 computer, using an editing program that displays the profile elevation-distance points on a printer plot. Obvious errors, such as points significantly displaced from the general trend of the profile, or possible errors of points less displaced, were noted. Copies of the data listing and a description of the possible errors were sent to the surveyors for correction or comment. When all errors were satisfactorily corrected, a final edit check was made before converting the data to magnetic-tape format.

Further quality control was made on the survey data during various stages of analysis. When anomalous results were obtained in a particular analytical step, an extensive check of the initial survey data was made, using the original field notebooks. The detailed quality control study of subsets of BEP profile data indicated that less than 1 percent of the surveyed points contained small-magnitude personal errors, and that most of the errors remaining in the data after standard editing were round-off errors in the elevations which did not affect the results.

2. Aerial Photos.

Aerial photos were used to determine beach changes both at single points through time and along the beach at one time. Dates of the photo missions are given in Table 5. Most of the flights originated near Sandy Hook and were flown at low tide. Contact prints of the original images were used with a scale of approximately 1:9600.

a. Base Map and Measurements. A Bausch and Lomb Zoom Transfer Scope, which allows the viewing of two separate images simultaneously, was used in the analysis. The operator viewed an aerial image and a base map of the same area and traced a superimposed image, such as the waterline, from the photo onto the map. Differences in scale and tilt were matched so the two images appeared superimposed. Thus, scale variation error and tilt errors were eliminated.

The base map was constructed to provide a constant scale for comparison of parameters between different sets of photos. Reference points on the base map

Table 5. Dates of aerial photo missions at Ludlam Beach.

Overflight time	Predicted low tide	Date	Overflight time	Predicted low tide	Date
1155	1618	26 Apr. 1974	----[1]	1346	24 Mar. 1963
1125	1147	23 Apr. 1971	1235	1334	4 May 1962
1220	1317	7 Mar. 1970	1410	1512	8 Mar. 1962
1045	1153	23 Oct. 1969	1320	1126	22 Sept. 1961
0950	1059	13 Apr. 1969	----	1123	7 June 1960
1210	1247	12 Apr. 1968	----	1244	22 Apr. 1959
----	1241	9 Jan. 1967	----	1015	29 May 1958
----	1305	4 May 1966	----	1309	21 Nov. 1957
----	1243	14 May 1965	----	1106	30 Apr. 1954
----	1153	10 Apr. 1964	----	1339	10 May 1952
			----	1254	21 Oct. 1949

[1]Not available. Most photos were obtained at low tide.

were road junctions observed on both the 1949 and the 1974 aerial photos. Road junctions were located in sufficient density near the beach so there were at least three easily locatable reference points on the base map per photo. The road junctions were near the average elevation of the island, which minimized relief displacement errors. The scale of the base map was slightly expanded to 1:9096 so all aerial photo scales would be smaller.

b. Quality Control. Stafford (1971) discusses errors inherent in aerial photos that can lead to misinterpretation. Because photos in this study were largely made under the same conditions, and because sand elevation differences on Ludlam Beach were less than 20 feet, such errors were minimized. Where measurements were compared, differences between repetitions were less than 10 percent of the differences measured between separate flights. Thus, errors in tracing images on the base map and in making the required measurements, were assumed acceptable.

IV. ANALYSIS AND RESULTS

The behavior of beach material on Ludlam Beach during the survey period (1962-72) was highly variable from profile line to profile line, and between surveys. However, when the survey data were averaged, such as by month, year, or by profile line, consistent trends in beach change appeared. Beach survey information data from the aerial photo analysis and wave data provided information on when, where, and how much beach material was eroded and deposited, and in what direction it was transported. The survey data also provided information on temporal and spatial changes in the position of the shoreline. (See App. A for the definitions of terms used in the analysis.)

1. Shoreline Shape.

Ludlam Beach is the middle of five barrier islands south of Absecon Inlet in New Jersey, each of which exhibit a characteristic concave seaward shoreline (Fig. 1). The shoreline protrudes seaward near inlets on either end of these islands, and is indented landward in the middle of the islands. The Ludlam Beach shoreline, as measured normal to a N. 30° E. axis of the island, is plotted in Figure 21. As shown, the shoreline is divided into five sectors: the north and south protrusions (the two inlet protrusions), the central protrusion (the protrusion of lesser magnitude in the center of the island), and the north and south indentations (the indentations north and south of the central protrusion). Figure 21 also shows the shoreline orientation at each profile line, measured relative to the axial line. With the exception of the profile lines near the inlets, the orientation of the shoreline is within 10° of the general orientation of the island.

The dotted curve in Figure 21 is an extrapolated shoreline extending about 300 feet landward of the central protrusion near the Sea Isle City groin field. The straight line distance between north and south protrusions is about 31,000 feet; the maximum amplitude from the line of the embayment between protrusions is about 1,600 feet at the north indentation. Measured from the Ludlam Beach axis, the north protrusion is greater than the south protrusion (1,770 versus 900 feet), a characteristic of barrier islands in southern New Jersey.

2. Profile Shape.

Profiles obtained in 1963, 1970, and 1971 for the months of January, March, April, August, and October are shown in Figures 22 to 25. The zero horizontal distance on the figures is the MSL shoreline intercept at the time the profile was obtained, removing the effect of net shoreline change. As shown, Ludlam Beach profiles are generally slightly concaved-up near the shoreline, with a summer and fall berm. The beach is backed by dunes except at the Strathmere and Sea Isle City bulkheads.

Two aspects of beach profile change are considered: (a) the change in shape of the profile, due to storms, accretionary periods, and seasonal and yearly sand redistributions; and (b) the change in position of the profile due to long-term erosion or accretion of the shore. The relatively high-frequency changes in profile shape are, thus, superimposed on the less rapid changes of the profile position. Figures 22 to 25 show the variation, if any, in profile shape, but not position, over an 8-year period.

The beach width averaged for 1963, 1970, and 1971, using the profiles in Figures 22 to 25, is illustrated in Figure 26. The seasonal change in mean beach width for all profile lines ranged between 258 and 267 feet. No significant change in mean beach width was observed between the 1963 and 1970 profiles. Beach width ranged from 90 feet (profile line 1) to 360 feet (profile line 5).

Changes in the foreshore slope along the coast are also shown in Figure 26 where the slope is taken as rise/run from the shoreline landward to the first noticeable change in topography. The mean slope of all profiles varied from 0.028 to 0.030 between the seasons given in Figures 22 to 25. Between the 1962-63 and the 1970-71 profiles, the average foreshore slope remained the same. The range of the average slope on different profile lines varied from 0.022 (profile lines 5 and 6) to 0.039 (profile line 1).

3. Shoreline Position Changes.

a. 1842-1955 Changes. Figure 27 shows the Ludlam Beach shoreline for six surveys from 1842 to 1955. The data indicate that the Ludlam Beach shoreline

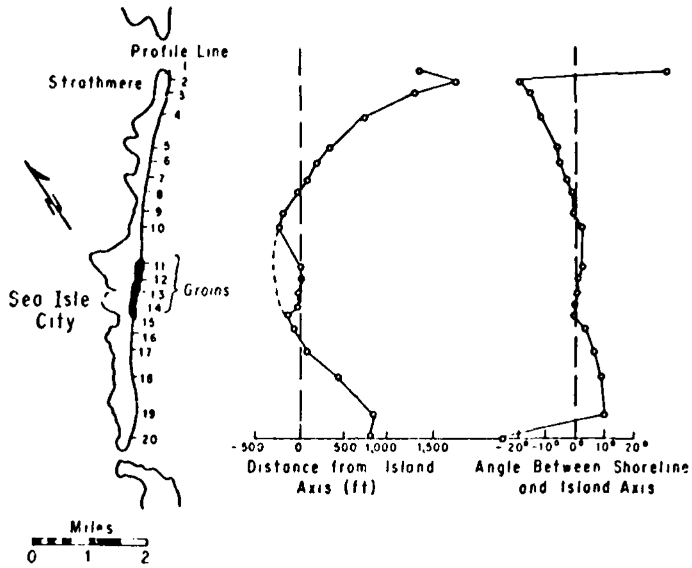

Figure 21. Shoreline orientation and shape of Ludlam Beach, showing the indentation near the island center and seaward projections of the shoreline near the inlets. The bulge near the island center coincides with the groin system at Sea Isle City.

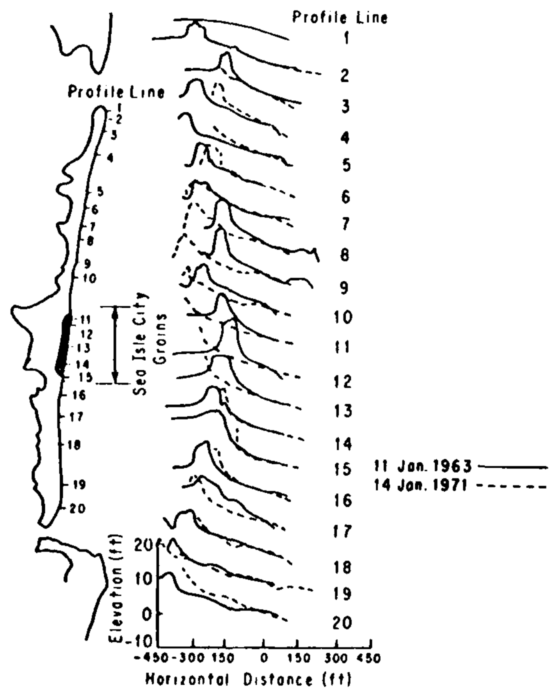

Figure 22. Superimposed beach profiles obtained from Ludlam Beach on 11 January 1963 and 14 January 1971. Horizontal distance is given seaward and landward of the MSL (NGVD of 1929) intercept of the profile at the time the survey was made.

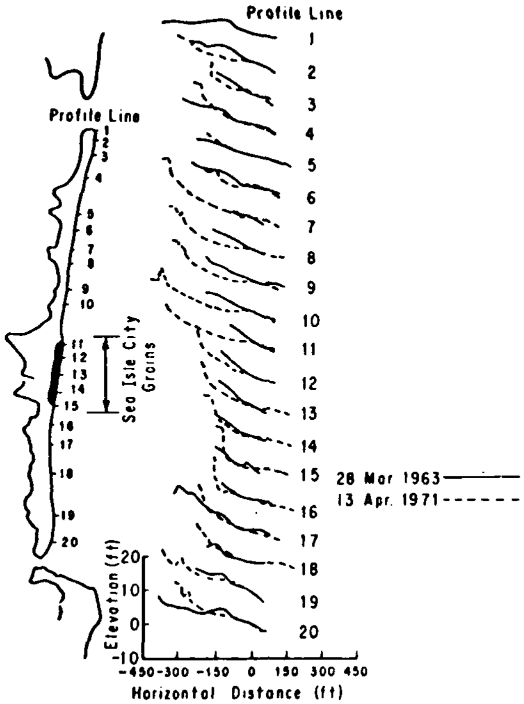

Figure 23. Superimposed beach profiles obtained from Ludlam Beach on 28 March 1963 and 13 April 1971. Horizontal distance is given seaward and landward of the MSL (NGVD of 1929) intercept of the profile at the time the survey was made.

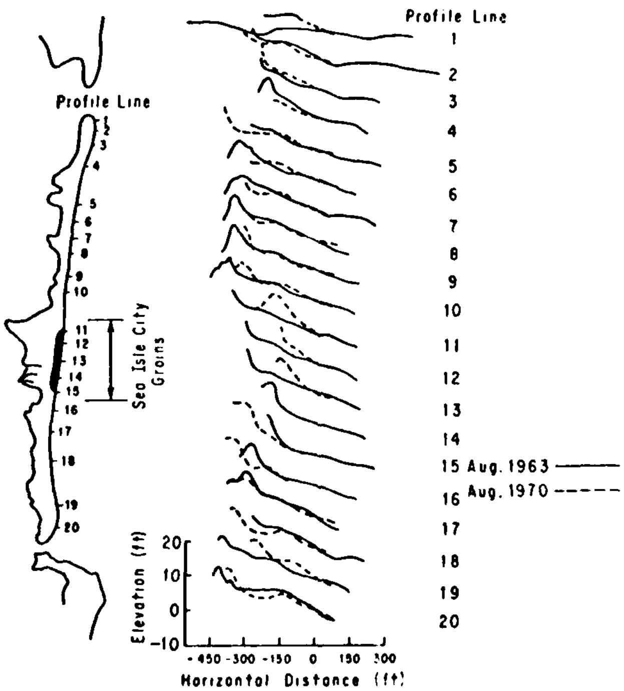

Figure 24. Superimposed beach profiles obtained from Ludlam Beach in August 1963 and August 1970. Horizontal distance is given seaward and landward of the MSL (NGVD of 1929) intercept of the profile at the time the survey was made.

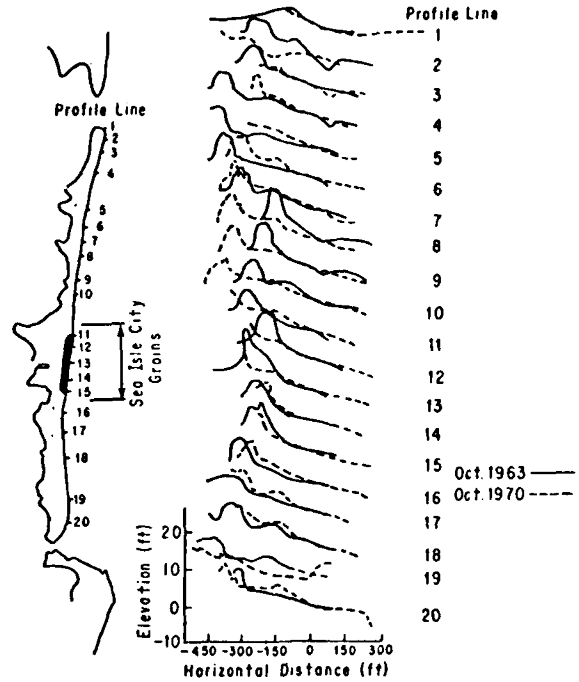

Figure 25. Superimposed beach profiles obtained from Ludlam Beach in October 1963 and October 1970. Horizontal distance is given seaward and landward of the MSL (NGVD of 1929) intercept of the profile at the time the survey was made.

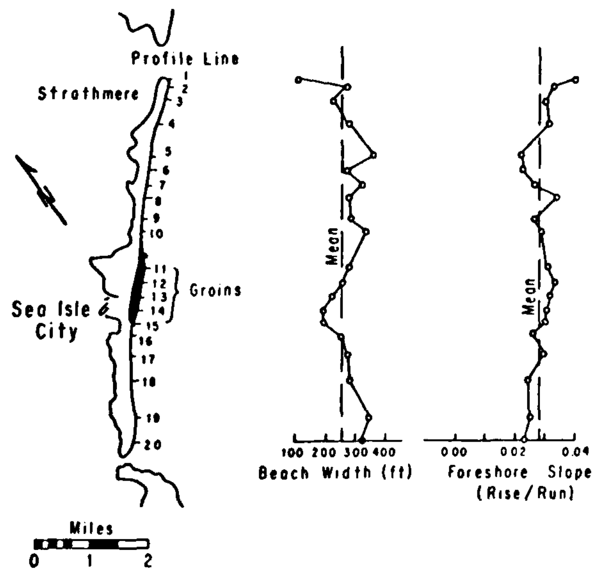

Figure 26. Average beach width and foreshore slope at profile lines in 1963, 1970, and 1971 on Ludlam Beach, showing a noticeable decrease in beach width from north to south through the groin fields.

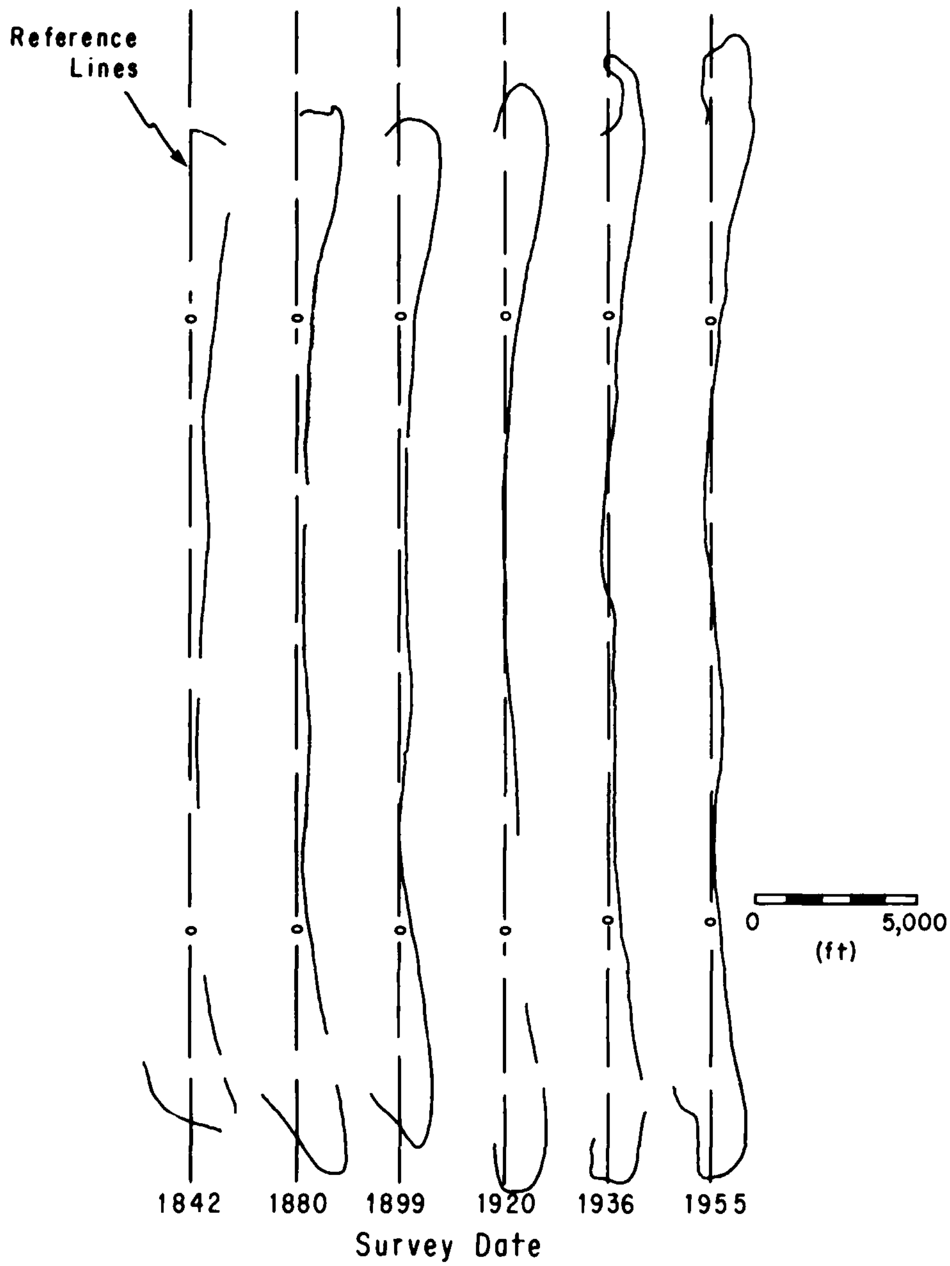

Figure 27. Shoreline position of Ludlam Beach as obtained from U.S. Coast and Geodetic Survey charts, 1842-1936, and a Corps of Engineers survey, 1955 (modified from U.S. Army Engineer District, Philadelphia, 1966).

north of Sea Isle City has been eroding at a rate of 3 to 5 feet per year, and at a lower rate south of Sea Isle City. In the past 130 years the length of Ludlam Beach has extended 2,300 feet northward at Corson Inlet and 1,000 feet southward at Townsend Inlet. The concavity of the island embayment has increased because the north and south protrusions at the inlets have remained relatively stable while the central part of the island, especially the northern half, has retreated perhaps 700 feet in places. The N. 30° E. orientation of the island has not varied noticeably since 1842.

b. <u>1949-74 Changes</u>. Shoreline positions over this 25-year period were measured from aerial photos and converted to rates of shoreline change (Fig. 28). The plotted rates are based on the changes in waterline and wetted boundary shorelines. In most cases, the changes from the wetted boundary shorelines were slightly less than the waterline position changes, but the trends were the same. Maximum erosion occurred in the north protrusion (near Corson Inlet) with intermediate erosion in the north and south indentations. Both the central protrusion (near the Sea Isle City groins) and the south protrusion (near Townsend Inlet) were nearly stable (see Fig. 4 for groin history).

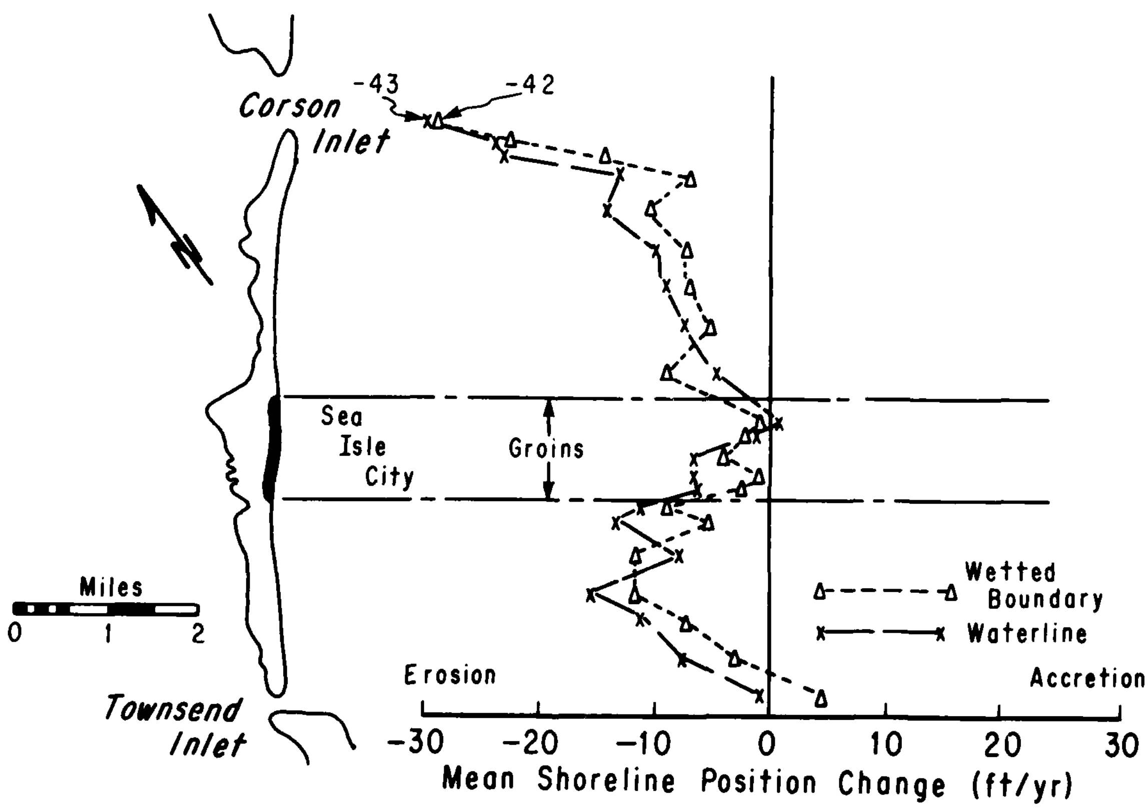

Figure 28. Shoreline change for Ludlam Beach, 1949-74 (obtained from 20 sequential sets of aerial photos).

c. <u>1962-72 Changes</u>. Shoreline position changes over this period were obtained from the BEP beach profiles. The shoreline position with time is plotted for each profile line in Appendix C; the cumulative rate of change at a profile line is plotted in Figure 29.

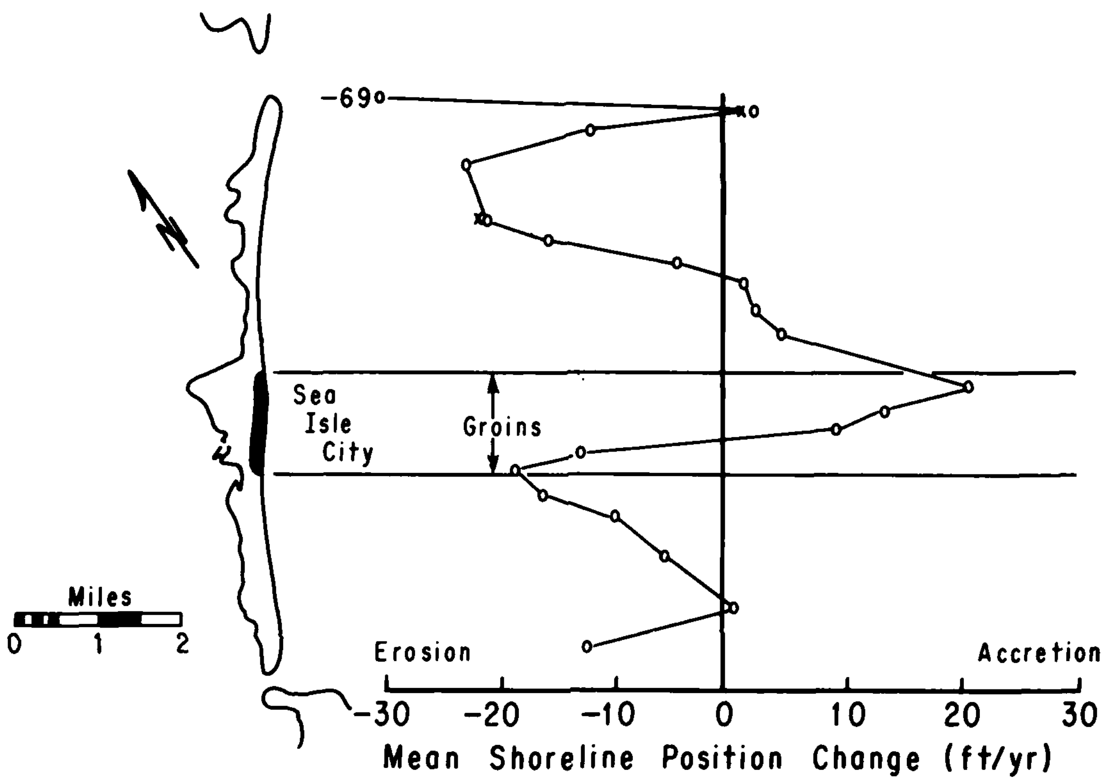

Figure 29. Yearly change in shoreline position on Ludlam Beach, obtained from BEP survey data, 1962-72. Note influence of Sea Isle City groins.

The rates of shoreline changes derived from 1962-72 beach profile surveys (Fig. 29) are comparable to the rates of shoreline changes derived from 1949-74 aerial photos (Fig. 28). As shown, the two sources of data yield similar magnitudes, with the rates of shoreline change ranging between -30 to +20 feet per year. Both data sources indicate erosion at the north and south indentations, but the 1962-72 profile data indicate less general erosion of the north protrusion and accretion at the updrift end of the central protrusion (the Sea Isle City groins). The accretion is a result of the newer groins constructed in 1967 (Fig. 6). The aerial photos, on the other hand, recorded changes over a longer time interval when the groins were in poorer condition and were not trapping sand as effectively.

For the 1949-74 aerial photo interval, the yearly mean shoreline retreat rate was 6.5 feet per year (Fig. 28) or 80 percent of the 1962-72 rate (8.2 feet per year). Sheridan, Dill, and Kraft (1974), using sediment core evidence, concluded that the position of the Delaware barrier island complex, 50 miles to the south, was 7.4 miles east of its present location 7,500 years ago. Thus, the Delaware shoreline retreat rate is computed as 5.3 feet per year, nearly the same as the 25-year (1949-74) value from Ludlam Beach.

d. Sea Level Rise Changes. Using tide gage records and coastal survey data obtained near Atlantic City from 1920 to 1970, Hicks (1972) determined sea level has been rising at a rate of 0.0146 foot per year (about 1.5 feet per century). On Ludlam Beach where the slope varies between 0.02 and 0.036 and averages 0.03 (Fig. 26), sea level rise will cause a shoreline retreat of between 0.7 and 0.4 foot per year, averaging 0.5 foot per year or approximately one-tenth of the 25-year rate indicated. These rates neglect any readjustment of the profile to sea level rise.

4. Volume Changes.

Cumulative changes in sand volume per lineal foot of beach above MSL are plotted in Appendix D. Four frequencies of beach volume change are identified in the survey data in Appendix D: (a) Changes caused by events (e.g., storms) between successive surveys, (b) monthly changes, (c) yearly changes, and (d) net changes over the 10-year study period.

a. Storm Changes. Seven storms occurred during the 1962-72 period for which poststorm surveys were available. The survey and storm dates, and the average MSL shoreline change and average volume change between surveys for each storm, are given in Table 6. MSL shoreline changes and volume changes for each storm by profile line are given in Figures 30 and 31. When weighted by the distance between profile lines, the average sand loss for the entire Ludlam Beach shore (2.3 cubic yards per lineal foot of beach) was 80,000 cubic yards per storm. The most severe storm loss occurred in March 1969; 4.6 cubic yards per foot, or a total 160,000 cubic yards, of Ludlam Beach sand was removed from above MSL. The average shoreline retreat resulting from this storm was 46.6 feet. Due to the rapid rate at which beach profiles have been observed to recover from storm erosion (e.g., DeWall, Pritchett, and Galvin, 1977; Birkemeier, 1979), these losses may be considered conservative estimates.

Table 6. Average shoreline and beach volume change for seven storms at Ludlam Beach.

Storm date	Survey dates		MSL change (ft)[1]	Unit volume change (yd^3/ft)[1]
	Before	After		
7-8 Nov. 1963	30 Oct. 1963	14 Nov. 1963	+1.5	-1.5
12-14 Sept. 1964	29 Aug. 1964	23 Sept. 1964	+24.5	-1.5
22-23 Jan. 1969	14 Jan. 1969	11 Feb. 1969	-3.9	-2.8
1-2 Mar. 1969	11 Feb. 1969	14 Mar. 1969	-46.6	-4.6
17 Dec. 1970	9 Dec. 1970	20 Dec. 1970	-9.2	-2.4
4 Feb. 1972	11 Jan. 1972	16 Feb. 1972	+14.0	-1.7
19 Feb. 1972	16 Feb. 1972	24 Feb. 1972	-5.0	-1.4

[1]Distance-weighted values.

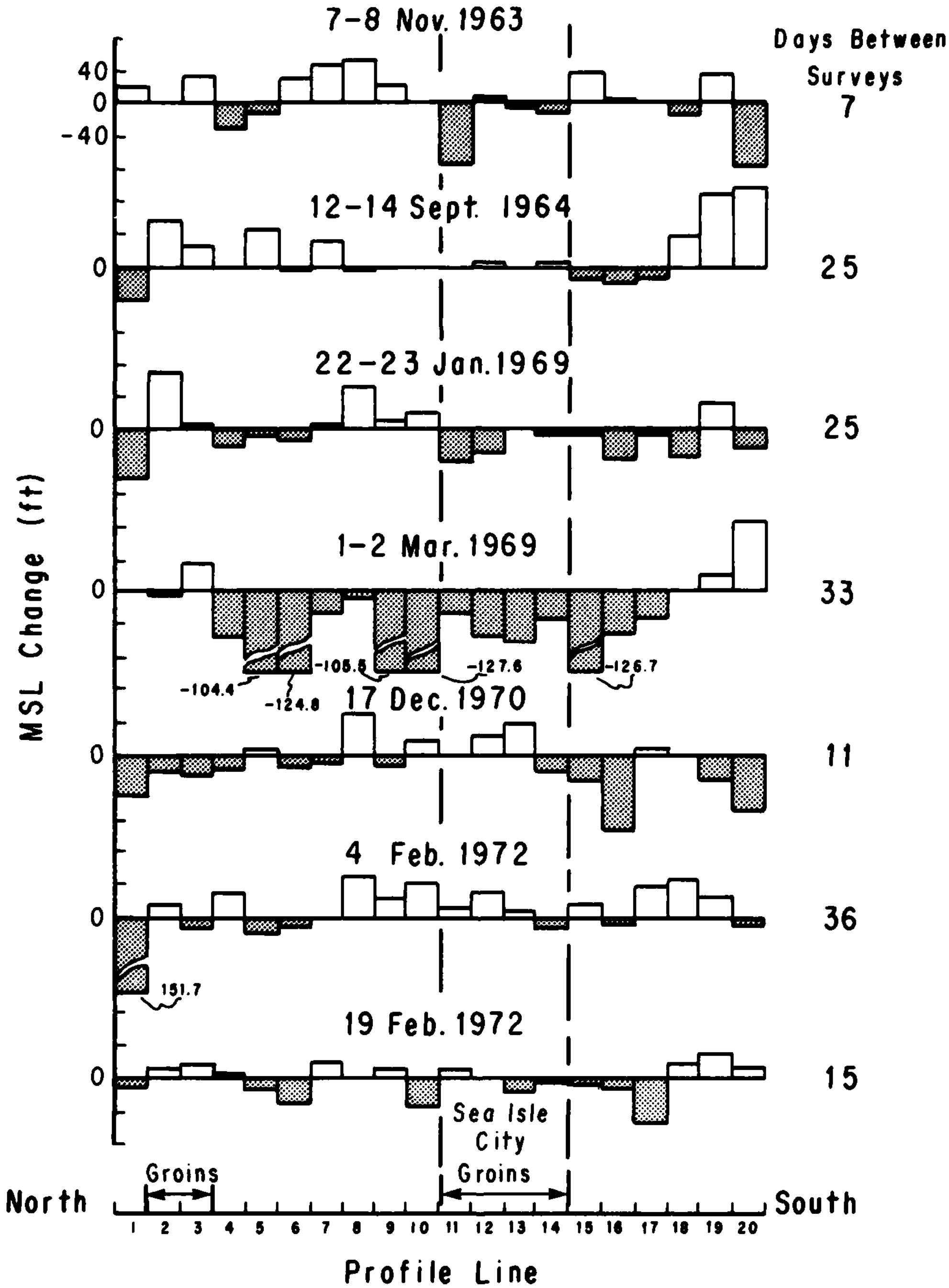

Figure 30. MSL shoreline changes resulting from seven storms at Ludlam Beach.

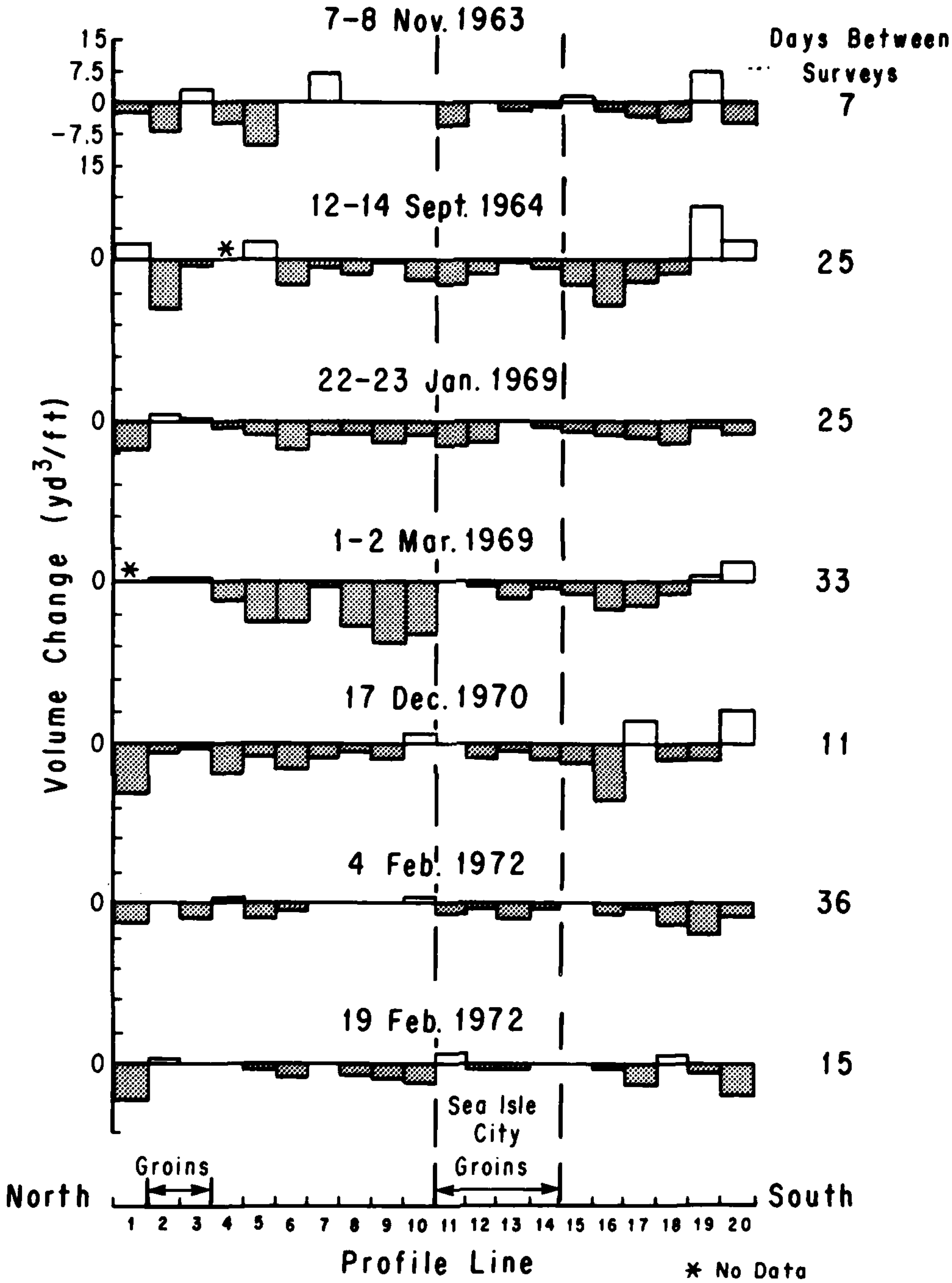

Figure 31. Beach volume changes resulting from seven storms at Ludlam Beach.

Sand volume changes for the seven storms are averaged by profile line in Figure 32. In general, the north end of the beach eroded while the south end accreted or remained stable during storms. The minimum sand loss occurred at profile lines within the two groin systems and near Townsend Inlet. Maximum losses occurred at Corson Inlet and the north and south indentations. The losses at the south indentation appeared related to the Sea Isle City groin field.

Maximum volume loss above MSL between any two successive surveys, regardless of time interval, is shown in Table 7 for each profile line. Some maximums were due to single storms and others were probably due to several events over a long period (up to 110 days). The greatest number of maximum losses occurred during fall and winter, when surveys were generally more frequent.

Table 7. Maximum beach loss data from Ludlam Island.

Profile line	Maximum volume loss (yd^3/ft)	Survey dates		No. of days between surveys
		Before	After	
1	19	14 Oct. 1970	10 Dec. 1970	57
2	20	5 Dec. 1964	18 Jan. 1965	44
3	17	6 Nov. 1962	9 Dec. 1962	33
4	20	7 Jan. 1964	15 Jan. 1964	8
5	16	21 Jan. 1967	4 May 1967	103
6	13	26 Jan. 1966	1 Apr. 1966	65
7	15	26 Oct. 1968	13 Nov. 1968	18
8	15	26 Oct. 1968	13 Nov. 1968	18
9	13	9 Feb. 1969	14 Mar. 1969	33
10	14	26 Oct. 1968	13 Nov. 1968	18
11	9	15 Oct. 1970	9 Dec. 1970	55
12	9	26 Oct. 1968	13 Nov. 1968	18
13	10	26 Jan. 1966	1 Apr. 1966	65
14	8	26 Jan. 1966	1 Apr. 1966	65
15	9	10 Mar. 1964	8 Apr. 1964	29
16	15	29 Aug. 1963	20 Sept. 1963	22
17	21	13 Sept. 1967	20 Sept. 1967	7
18	15	7 Jan. 1964	15 Jan. 1964	8
19	16	23 Sept. 1964	5 Dec. 1964	73
20	22	8 Oct. 1967	26 Jan. 1968	110

b. Monthly Changes. Clear trends in the relative volume of sand above MSL and in the position of the shoreline on Ludlam Beach are evident when averaging data by survey month. Figure 33 illustrates the cumulative volume, based on all surveys in a given month, averaged for all profile lines and plotted relative to the yearly average on 1 January with the net yearly change removed. A net accretion between months occurred between March and July. During each of the remaining 7 months the monthly change was negative and the result was a decrease in the cumulative sand volume on the beach.

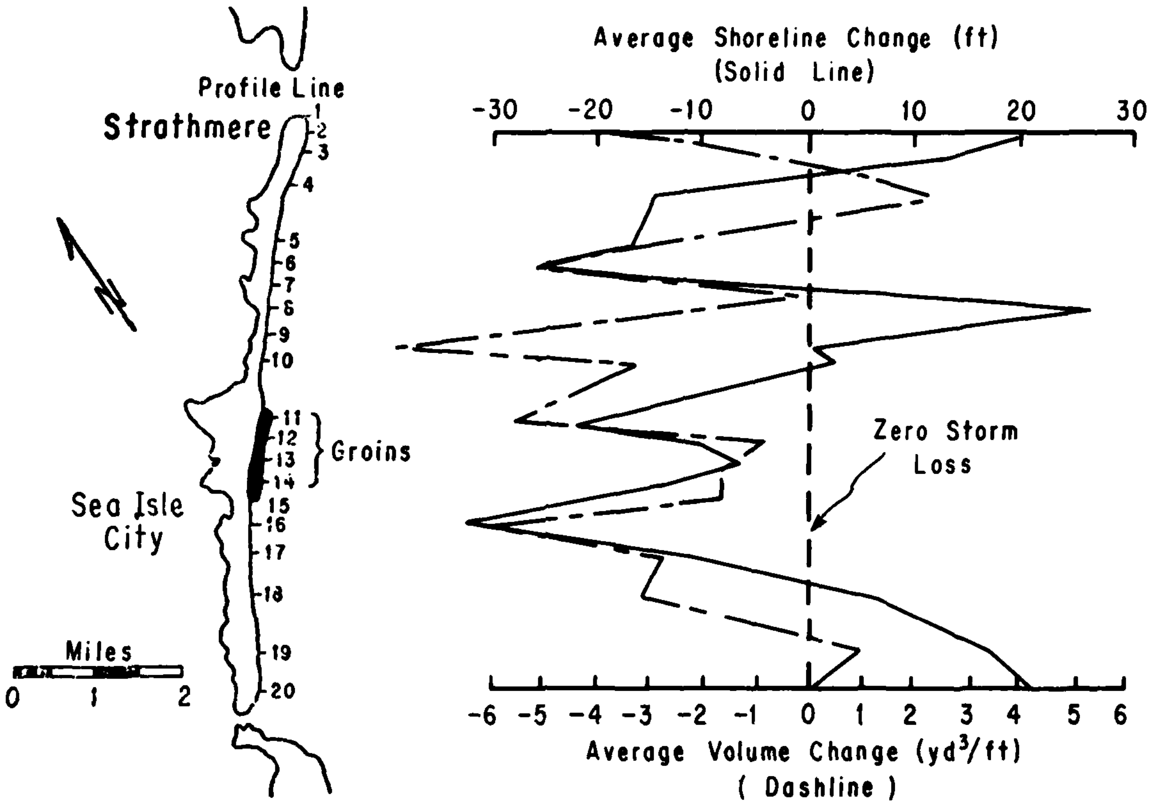

Figure 32. Shoreline and beach volume changes averaged for seven storms at Ludlam Beach, showing the large changes which occurred near Corson Inlet and the apparent effect of the Sea Isle City groins in reducing storm losses from above MSL.

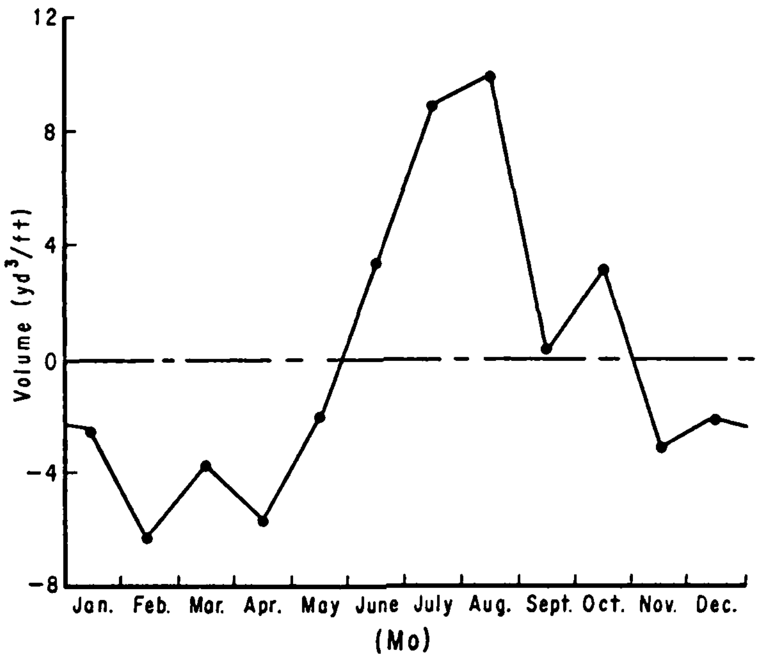

Figure 33. Cumulative volume of sand on Ludlam Beach, based on a 10-year monthly average.

The periods of minimum and maximum sand volumes on Ludlam Beach were November through May and June through October, respectively. The positive month-to-month change (Fig. 33) in May, June, and July was greater in magnitude than the negative change in volume between months in the fall and winter. The largest average monthly changes in sand volume above MSL were accretional (5.3 cubic yards per foot-month during June, Fig. 33). The maximum monthly loss rate was 4.4 cubic yards per foot-month in August. The monthly data were widely scattered. Each year did not exhibit the seasonal exchange trend shown in Figure 33 which is the average of one mode of oscillation of sand storage on the beach. Consequently, the seasonal losses and gains should be considered more of a tendency than a cycle.

A plot of the mean monthly shoreline position is similar to the volume changes shown in Figure 33. The mean range between maximum retreat and advance was 50 feet.

When mean monthly changes in sand volume and shoreline position were plotted by profile line (Fig. 34), several variations were observed. For example, between April and May sand eroded at Corson Inlet and accumulated at Townsend Inlet. From June to July the direction of the changes reversed at the two inlets. From September through December the monthly changes near Corson Inlet were also opposite in sign to those at Townsend Inlet.

Based on a referenced zero sand volume on the beach on 1 January, the mean cumulative sand volume for each profile line, obtained by averaging all volumes obtained by surveys for that month, is shown in Figure 35. As shown, the sand volume maximums and minimums generally occur at about the same season on all profile lines. An exception occurs between profile lines 8 and 13, just north

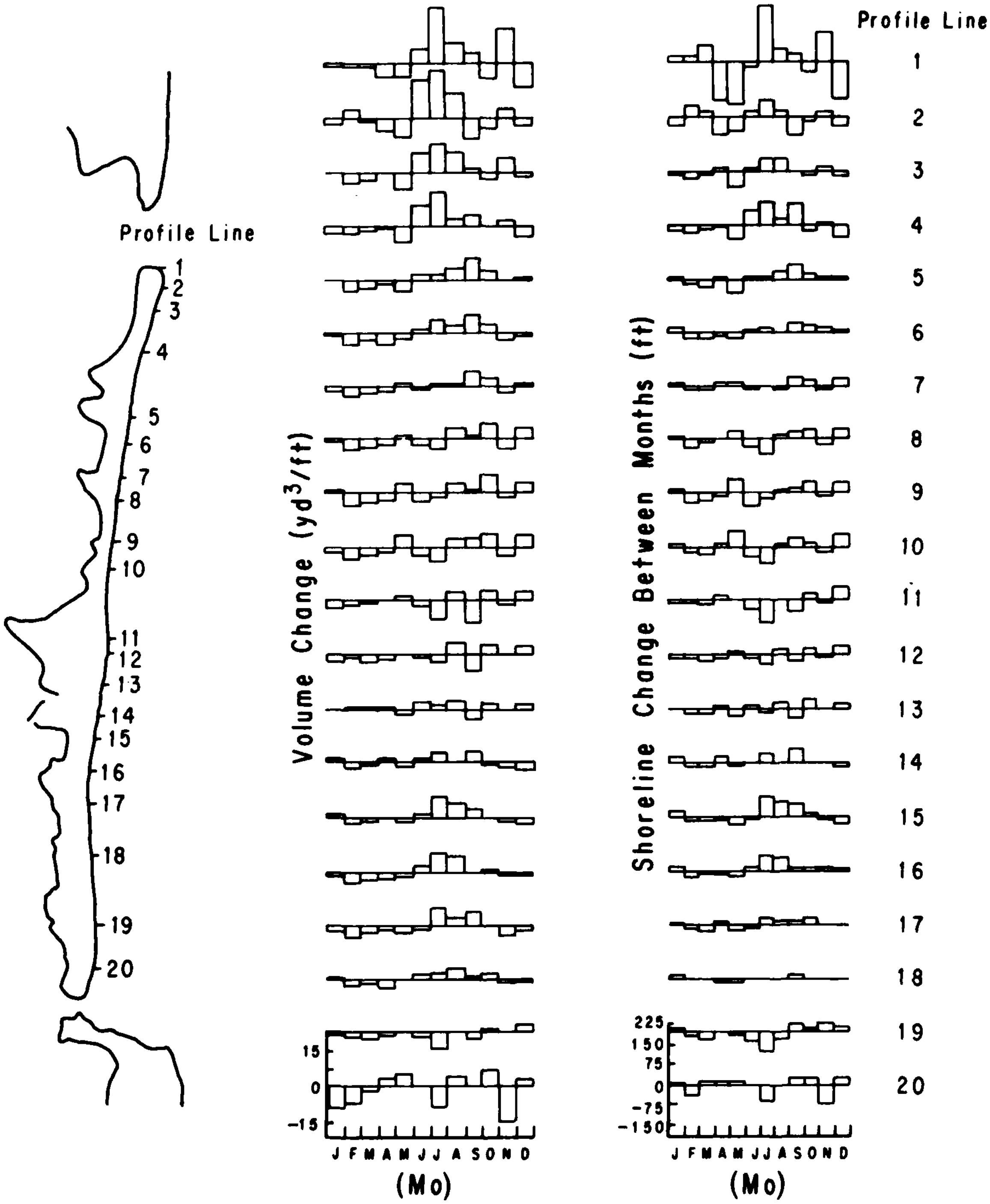

Figure 34. Monthly sand volume and shoreline position change at Ludlam Beach. Note the direct relationship between the two parameters.

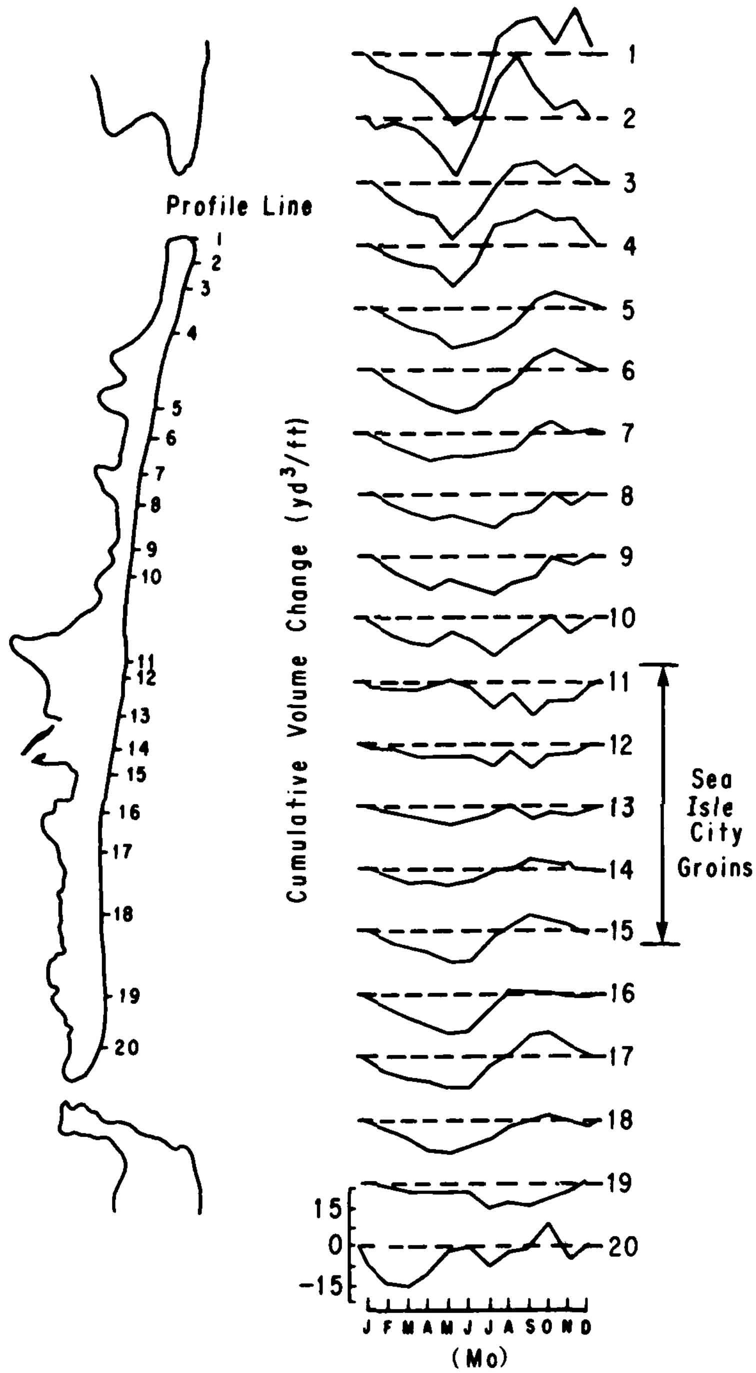

Figure 35. Monthly cumulative sand volume change at 20 profile lines on Ludlam Beach. Note distinct similarity in monthly change along the coast.

of the Sea Isle City groin field and within the groin field, where the yearly maximum sand volume is generally during December. The range between the summer maximum and the winter minimum, which usually precedes it by 6 months, is illustrated in Figure 36. The average difference between the minimum sand volume (February) and the maximum sand volume (August) was 18 cubic yards per foot. For the same survey period at Atlantic City, which included two artificial beach fills, Everts, DeWall, and Czerniak (1974) calculated a seasonal sand volume range of 24.5 cubic yards per foot, somewhat larger than that observed at Ludlam Beach. Shepard (1950) also observed similar seasonal changes in beach profiles along the coast of southern California.

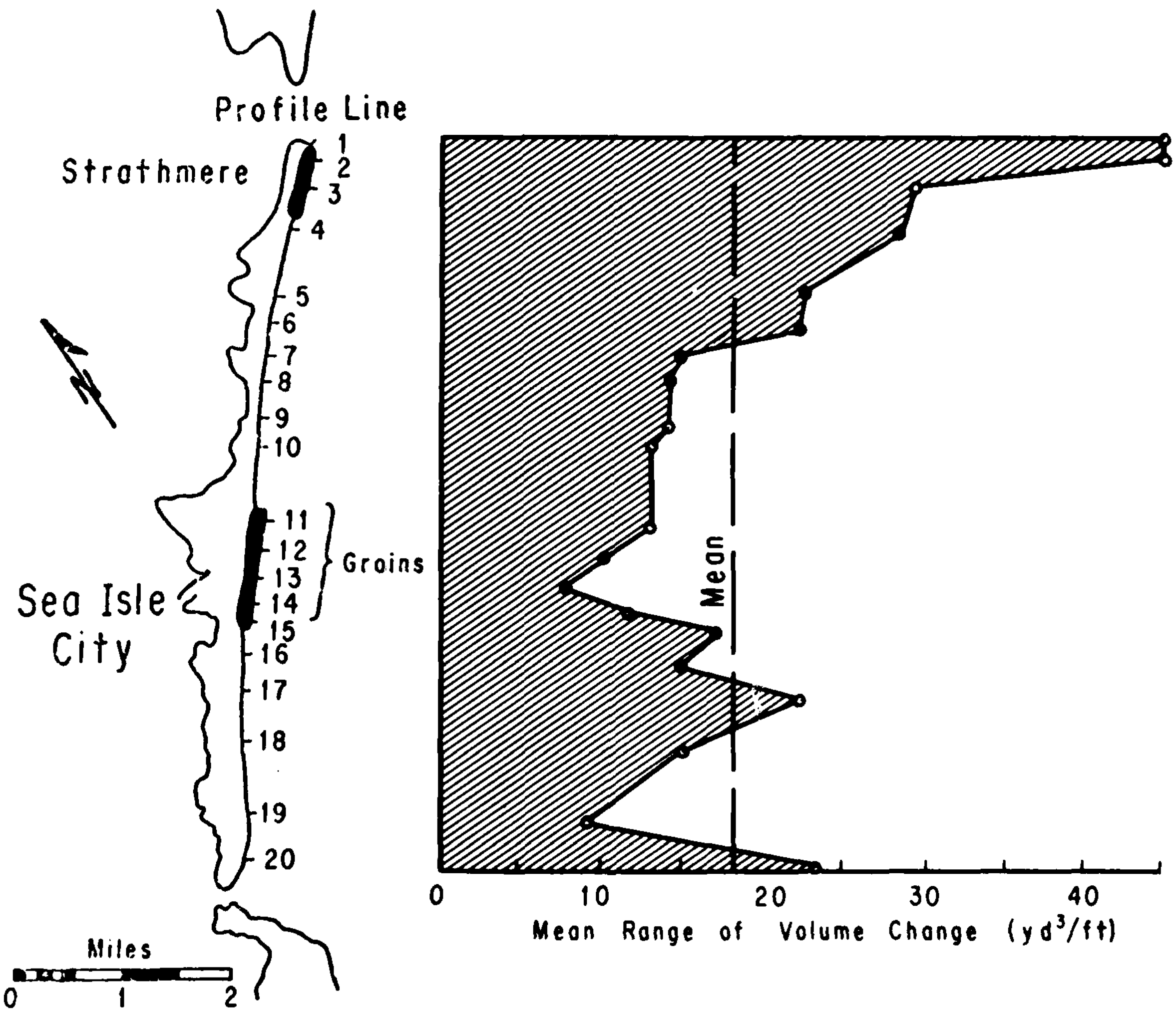

Figure 36. Sand volume change from yearly minimum to yearly maximum at Ludlam Beach.

c. Yearly Changes. A notable year-to-year variation in sand volume above MSL and in shoreline position was measured on Ludlam Beach (Fig. 37). Yearly changes varied from a gain of 2.9 cubic yards per foot between 1964 and 1965 to a decrease of 4.6 cubic yards per foot from 1966 to 1967. This corresponds to the net 100,000 cubic yards gained at Ludlam Beach in 1965 and the 160,000 cubic yards lost in 1967. An unknown part of the 1965 volume increase resulted from a dune rebuilding program after a September 1964 storm. The cumulative sand volume from 1962 to 1972, and referenced to zero in 1962, is illustrated as a solid line on the figure.

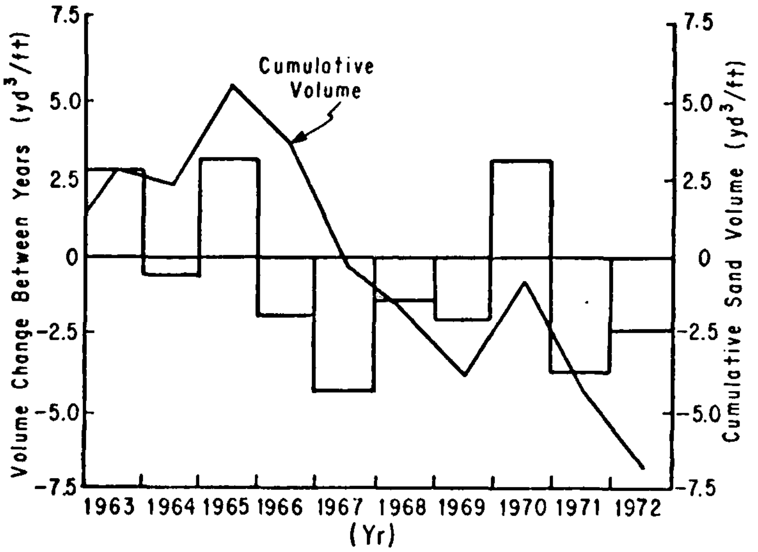

Figure 37. Yearly volume change and cumulative volume above MSL at Ludlam Beach, showing extreme variability between years.

Changes in the MSL shoreline intercept were similar to yearly changes in sand volume above MSL. Figure 38 shows the shoreline position change between years and the cumulative shoreline change over the 10-year study period. (Shoreline position was computed by weighting by distance between profile lines; the MSL shoreline position obtained from each profile line for each survey, then averaging the survey averages for a given year.) Between years, the maximum shoreline retreat was 23 feet. The maximum yearly progradation was 16 feet.

d. Net 10-Year Change. The average long-term rate of sand loss was 1.12 cubic yards per foot-year as determined by a linear regression fit to the cumulative volume line (Fig. 39). The equation of the regression line is

$$V_y = -1.12(Y - 1962) + 5.8 \qquad (1)$$

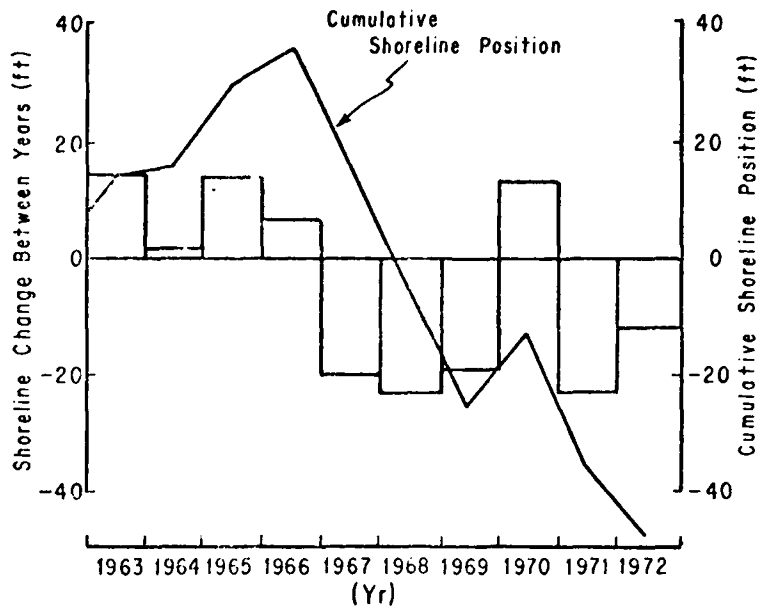

Figure 38. Yearly shoreline position change and cumulative shoreline position at Ludlam Beach, referenced to zero positon in 1962.

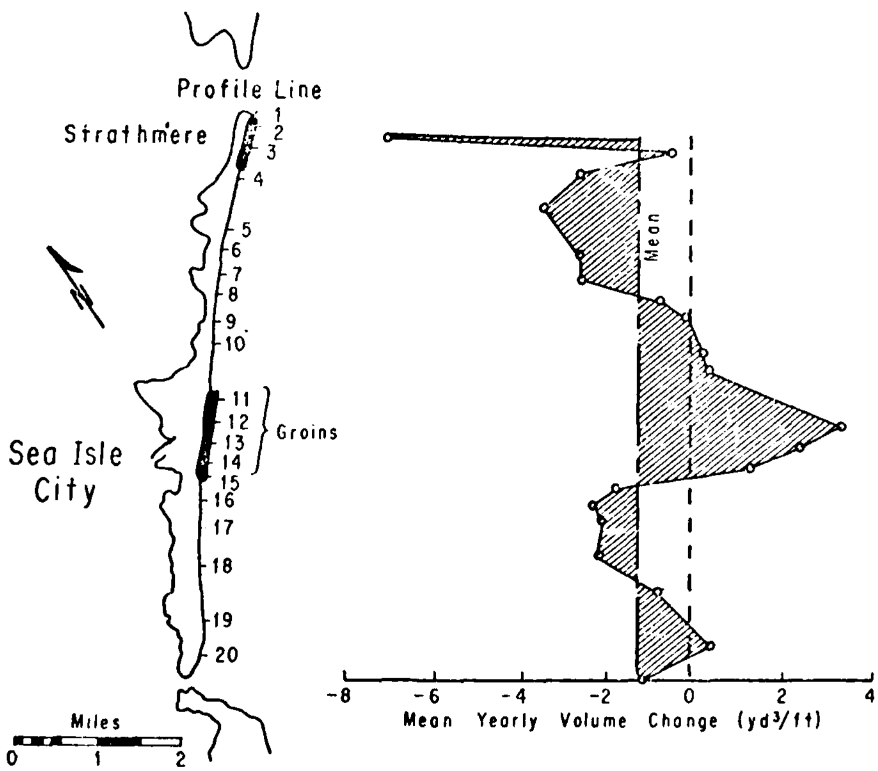

Figure 39. Mean yearly volume change at Ludlam Beach (1962-72), showing accretion in the northern part of the Sea Isle City groin field.

where V_y is the mean sand volume loss or gain (in cubic yards per foot-year) since 1962, based on the linear regression computation, and Y is the year. Note the small net annual erosion rate when compared to the wider fluctuations which occur seasonally (Fig. 33) and as a result of storms (Fig. 32). The correlation coefficient for equation (1) is -0.88. Thus, 77 percent of the variation in mean yearly volume change is accounted for by the linear relationship in different years. Everts, DeWall, and Czerniak (1974) obtained a mean yearly sand loss rate about twice as great for the beach at Atlantic City (2.1 cubic yards per foot-year).

Large variations in the mean yearly volume change along the length of Ludlam Beach (Fig. 39) ranged from a net loss of -6.8 cubic yards per foot-year at Corson Inlet to a gain of +3.3 cubic yards per foot-year at the northern part of the Sea Isle City groins. The area near Townsend Inlet was nearly stable while the indentations between the inlets and the Sea Isle City groins experienced loss rates averaging -2 to -3 cubic yards per year-foot.

5. Alongshore Redistribution of Beach Material.

The mean change in yearly sand volume and shoreline position on Ludlam Beach was not similar (Figs. 40 and 41). Sand volume increased and decreased in a time-ordered sequence from north to south during the 10-year study. Periods of shoreline advance alternated with periods of shoreline retreat, and volume changes indicated beach material moved alongshore and above MSL in "humps" or waves. This movement, in a time-ordered sequence, is plotted by a visual fit on the figures. A solid line indicates the movement through time, from north to south, of a volume maximum or hump. Dashlines indicate the progressive southward shift of the volume minimum (yearly mean loss). The dotted lines follow the yearly position of the zone of approximately no volume change along the coast. Note that the interval between each profile line histogram on Figures 40 and 41 is not plotted to scale. This, however, does not mask the alongshore distribution of the volume or shoreline trends through time. It does allow the histograms to be fitted on the figures. The yearly change in shoreline position and sand volume is largest at profile lines near Corson Inlet.

6. Profile Envelopes.

Profile envelopes are bounds, which enclose the maximum measured profile variations for each profile line, and are the upper and lower limits of change experienced by a beach profile for a finite number of surveys during a specified time interval. When plotted, the data provide an easy means of determining the lower and upper profile extremes, and the landward bound for elevation and contour intercept changes. The plots may also indicate accretion or erosion trends.

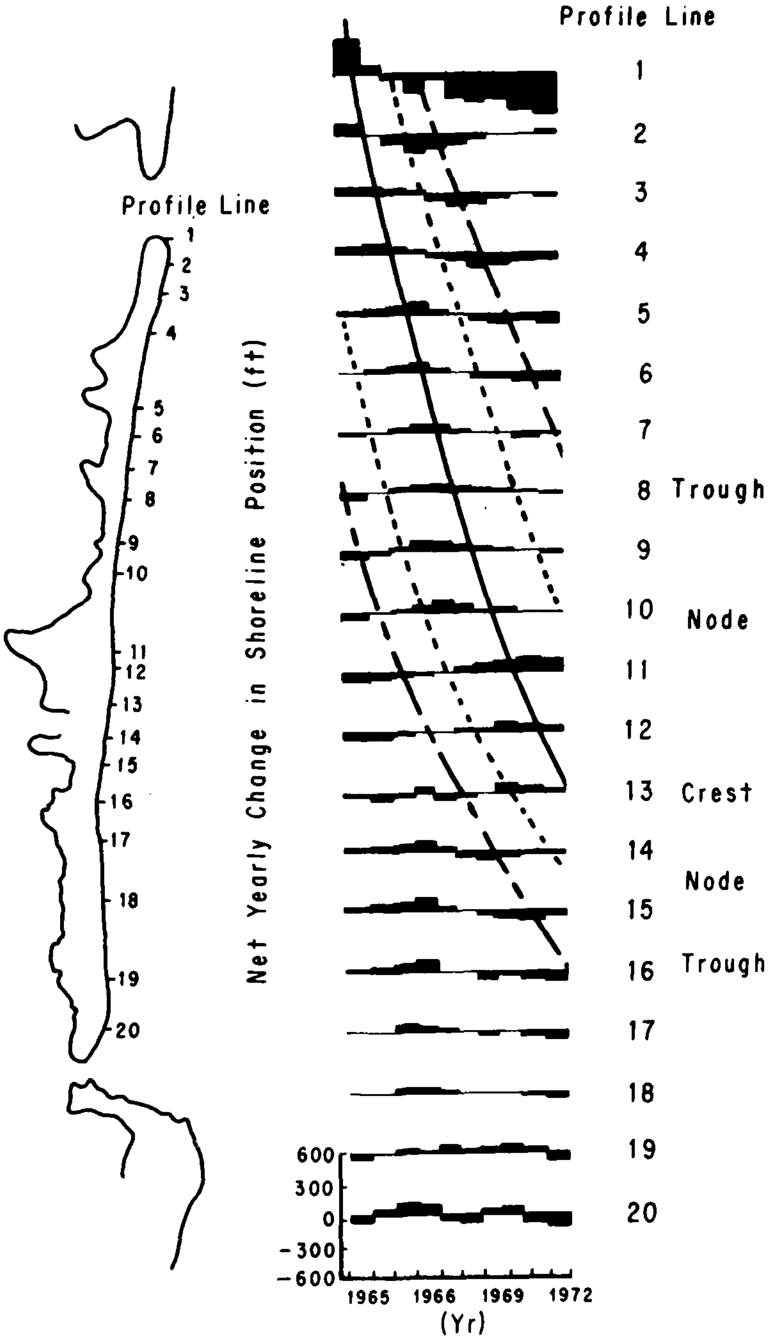

Figure 40. Yearly change in shoreline position on Ludlam Beach, illustrating the progressive shift of the shoreline seaward (solid line) through time and from north to south along the coast. Dashlines indicate a shift landward; dotted lines identify the position of the shoreline node.

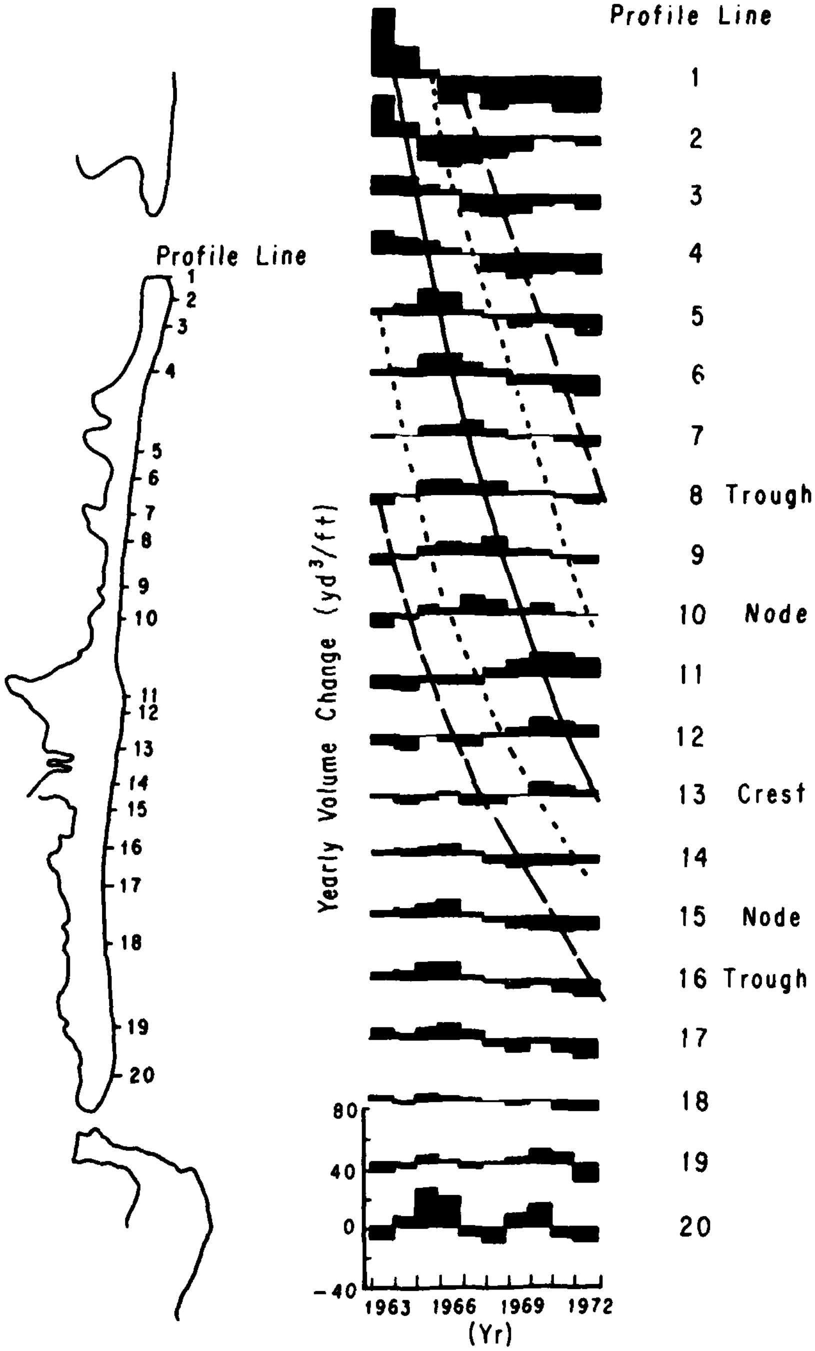

Figure 41. Yearly change in mean sand volume on Ludlam Beach, showing a shift, through time, of the volume maximum to the south.

Profile envelopes are useful in many aspects of coastal engineering planning and design; e.g., in the siting and design of structures such as groins or bulkheads on a beach, and in determining the depth to bury a cable on an upper beach so that it will not be uncovered. Envelopes are also useful in determining the range of erosion and the subsequent natural recovery expected to restore a beach, and as an aid in determining the need to replenish a beach at a given time.

Upper and lower bounds of each envelope do not represent single surveyed profiles. They are the resultant outline of the maximum and minimum elevations as computed for all the profiles at fixed horizontal stations 10 feet apart. A single line on the landward or seaward extremity of some envelopes may indicate that only one profile contributed to the envelope at that location. This occurs because some surveys do not extend as far seaward as others. Since many of the Ludlam Beach surveys did not extend much below MSL, the subsequent analysis of these envelopes only includes the area above MSL.

Figures 42, 43, and 44 show profile envelopes constructed from the 10 years of survey data collected between 1962 and 1972. Zero distance on the horizontal axis references the shoreline position as established during the first survey in October 1962. The lower envelope bound is MSL. For profile line 1, the landward closure is approximately 1,600 feet landward of the zero distance (Fig. 42). Maximum horizontal and vertical excursions for profile lines during the 10-year period are given in Table 8. The elevation of the maximum horizontal distance was at MSL on all but two profile lines.

Table 8. Horizontal and vertical 10-year excursion maximums for profile lines on Ludlam Beach.

Profile line	Maximum horizontal range (ft)	Elevation of maximum horizontal range (ft)	Maximum vertical range (ft)	Location of maximum vertical range[1] (ft)
1	930	0	7	-700
2	360	0	15	-250
3	275	0	14	-250
4	310	0	10	-300
5	250	0	6	-200
6	320	0	6	-175
7	225	2	5	-125
8	300	0	6	0
9	350	0	6	0
10	320	0	6	-25
11	320	0	7	-150
12	200	0	10	-200
13	200	0	8	-225
14	250	0	10	-225
15	275	0	13	-225
16	275	0	13	-275
17	200	0	6	-200
18	175	0	5	-150
19	230	0	7	-375
20	500	6	11	-150

[1]As measured from the MSL shoreline position at the first survey (see tick marks on Figs. 34, 35, and 36).

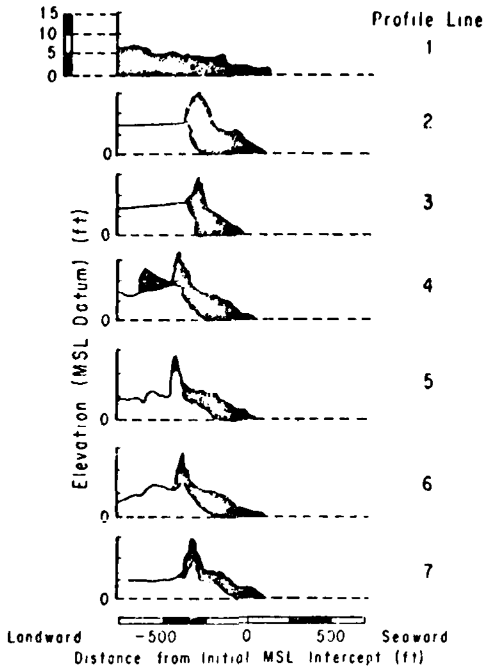

Figure 42. Envelopes for profile lines 1 to 7 at Ludlam Beach, 1962-72.

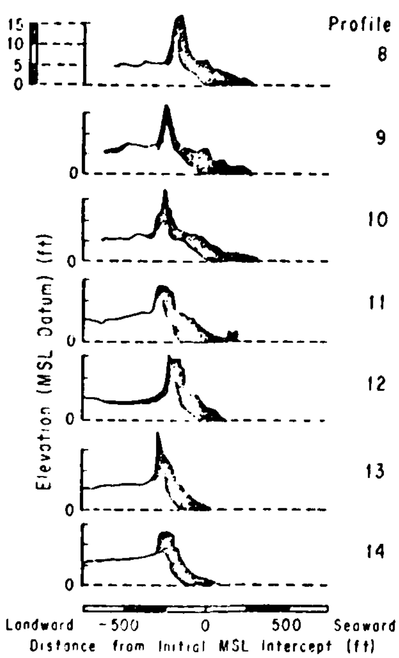

Figure 43. Envelopes for profile lines 8 to 14 at Ludlam Beach, 1962-72.

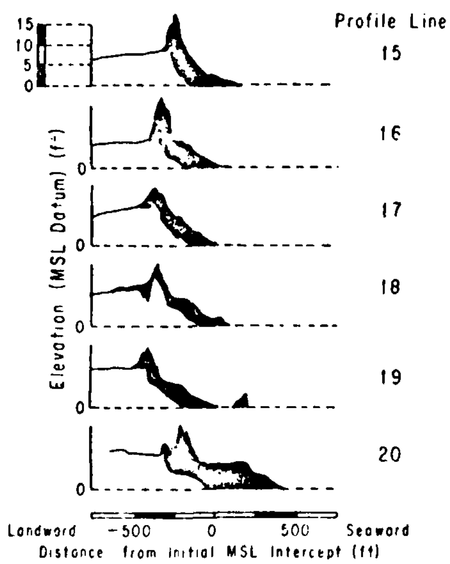

Figure 44. Envelopes for profile lines 15 to 20 at Ludlam Beach, 1962-72.

Figure 45 illustrates the maximum horizontal excursion of contours at and above MSL, in both seaward and landward directions, which occurred over the 10-year study period. The tick marks show the MSL shoreline intercept at the first survey. The horizontal excursion of the beach below 8 feet was nearly twice as large at profile line 1 as it was elsewhere, except at profile line 20. The shape of the excursion curves was similar on most profile lines with the maximum horizontal excursion of 200 to 300 feet at MSL.

7. Overwash Deposition.

Overwash, the movement of wave uprush and sediment past the normal extent of the beach, often through a breach in the frontal dune, occurs only during the most severe storms at Ludlam Beach. Overwash results from high water caused by storm surge and high tides. The importance of overwash is that it moves locally derived dune and beach sand landward. Sand moving alongshore from other sources may also be moved landward. Deposits are thin and sheet-like, sometimes extending completely across the island. Although overwash can damage structures such as buildings and roads, the sand it deposits is usually accessible for returning to the beach. Historical data on the frequency of occurrence of storms producing significant overwash deposits in southern New Jersey are not available.

Only one large overwash event has occurred in the Ludlam Beach area since 1949. This resulted from the severe extratropical cyclone of 6 to 8 March 1962. Five near-record tides were measured during its destructive 60-hour life. Sea Isle City and the region north to Strathmere suffered near complete destruction because of tidal flooding and overwash.

The series of air photos obtained at low tide on 8 March were analyzed to determine the areal extent of the overwash deposit (Fig. 46). Assuming a beach width of 260 feet, and a dune width of 100 feet, i.e., where erosion, not deposition occurred, the surface area of the overwash deposit on Ludlam Beach was 1,150,000 square yards. Further, assuming a deposit depth which averaged 1 foot, the total loss from the beach system and gain by the island was 385,000 cubic yards. Because the deposit depth is only a guess based on ground photos taken before the sand was removed and because the amount of material deposited in Ludlam Bay is unknown, the loss value could vary by 100 percent. The calculated overwash where it occurred was 14.7 cubic yards per foot. Since the 1962 storm was an extreme, the overwash values are also probably an extreme. Overwash values cannot be predicted so the yearly loss by overwash cannot be estimated.

8. Submarine Bars.

Submarine bars along the southern New Jersey coast appear to be seasonal features formed in the fall and winter as sand is removed from the subaerial beaches. Subsequently, the bars reduce in volume as the sand moves landward from the offshore region in the late spring and summer, thereby rebuilding the beach. The most pronounced bar presence is probably late winter when the beaches above MSL are most depleted. The least sand volume in bars is probably in early fall when there is maximum sand volume on the beach.

Beach surveys extended only -1 to -2 feet below MSL, not deep enough to intercept the submarine bars. An analysis of the aerial photos was made to

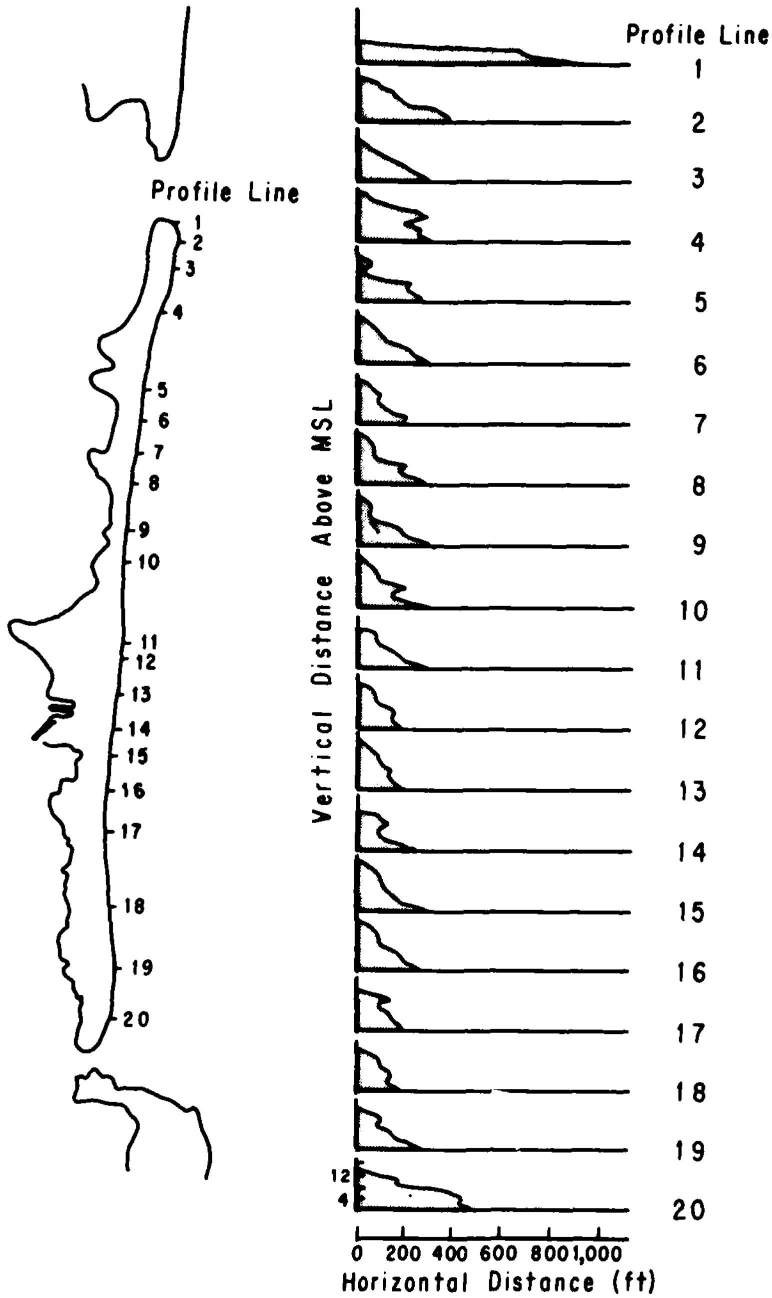

Figure 45. Maximum horizontal excursion of contours above MSL at 20 profile lines on Ludlam Beach, 1962-72.

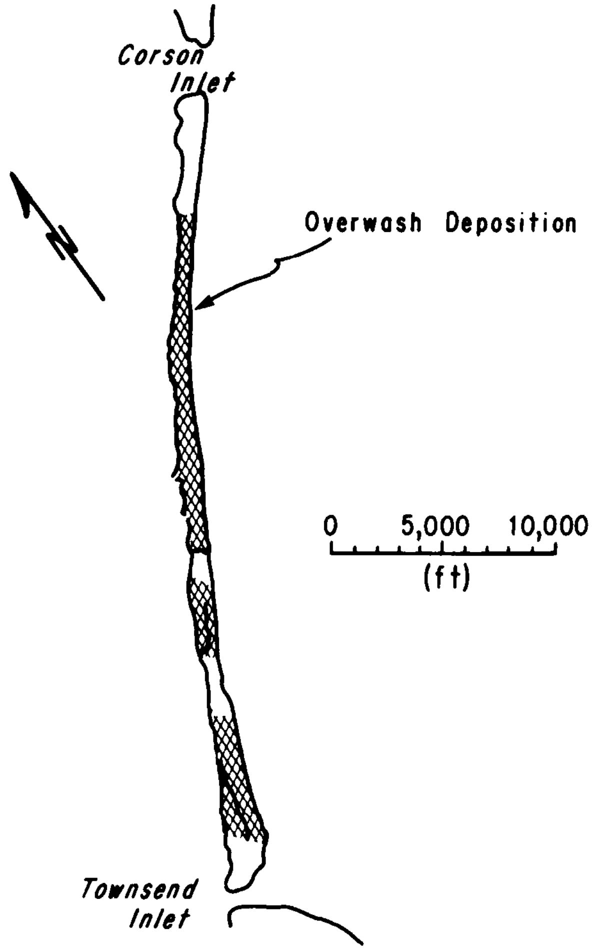

Figure 46. Overwash deposition on Ludlam Beach as a result of the 6 to 8 March 1962 storm. Where overwash occurred, 14.7 cubic yards per foot of sediment was moved landward from the beach, in some places more than 1,000 feet.

determine the persistence, orientation, distance from shore to the bars, and approach direction of waves breaking on the bars. The photos provided only a two-dimensional view of the bars because of the general inability to penetrate the water surface. In some instances bar presence and characteristics were inferred from the breaking wave pattern. The major value of the aerial photos was in qualitatively determining the variation in bar characteristics along the coast, rather than in establishing the magnitude of various bar parameters.

Figure 47 shows the orientation of submarine bars during three aerial photo missions (1959, 1962, and 1968) in the months of March and April when the bars were well pronounced. The figure also shows that submarine bars generally trend at a slight angle to the coast, becoming more distant in a southerly direction. Since most of the analyzed aerial photo sets were taken in the late winter and spring (Table 5), the presence of bars in the sample of 20 photo sets is probably greater than the yearly average.

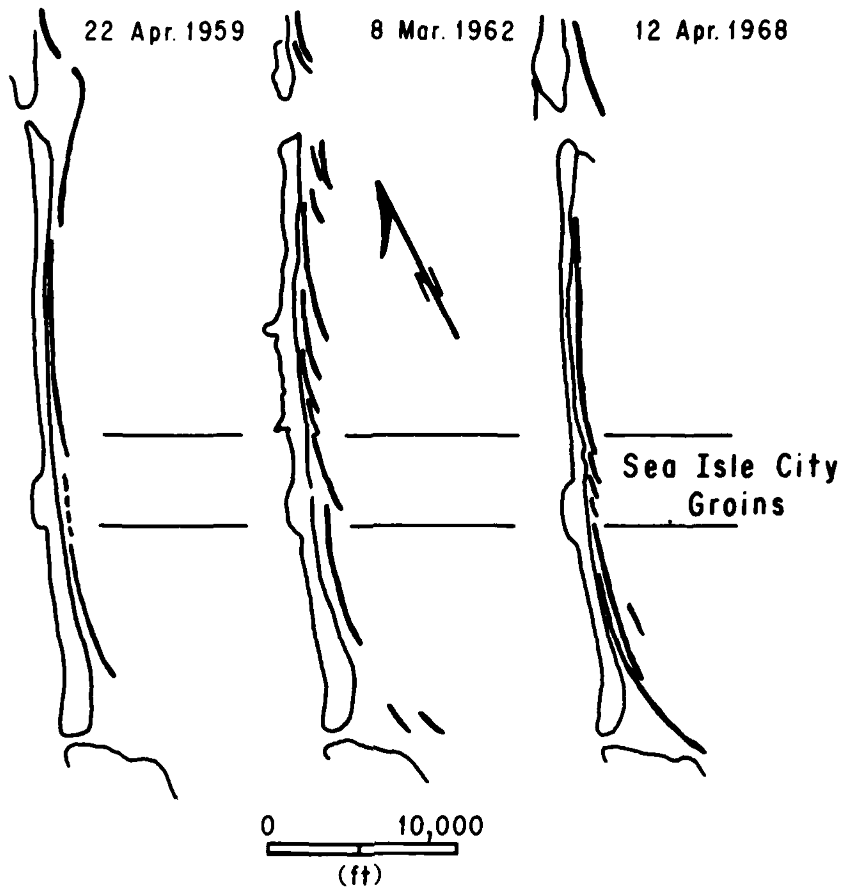

Figure 47. Submarine bar (heavy solid lines) characteristics during the spring of two typical years (1959 and 1968) and just after a severe storm (1962).

Bar presence appears to vary considerably along Ludlam Beach. Figure 48 illustrates the percent of time submarine bars were present in the 20 aerial photo sets and the percent of time the submarine bars intersected the coast. Bars were most persistent near the inlets and in the coastal indentations separating the Sea Isle City groins from the inlets. Bars were observed off the Sea Isle City and Strathmere groins in less than 30 percent of the aerial photos. The intersection of bars usually occurred at the southern end of the groin system.

Ridge-and-runnel systems differ from submarine bars in where they are located. Bars are located seaward of the foreshore; ridge-and-runnel systems are troughs and ridges at the foreshore. They generally indicate an accretionary phase on the beach as material from offshore migrates landward on the foreshore as discrete ridges. The presence of ridge-and-runnel systems at various

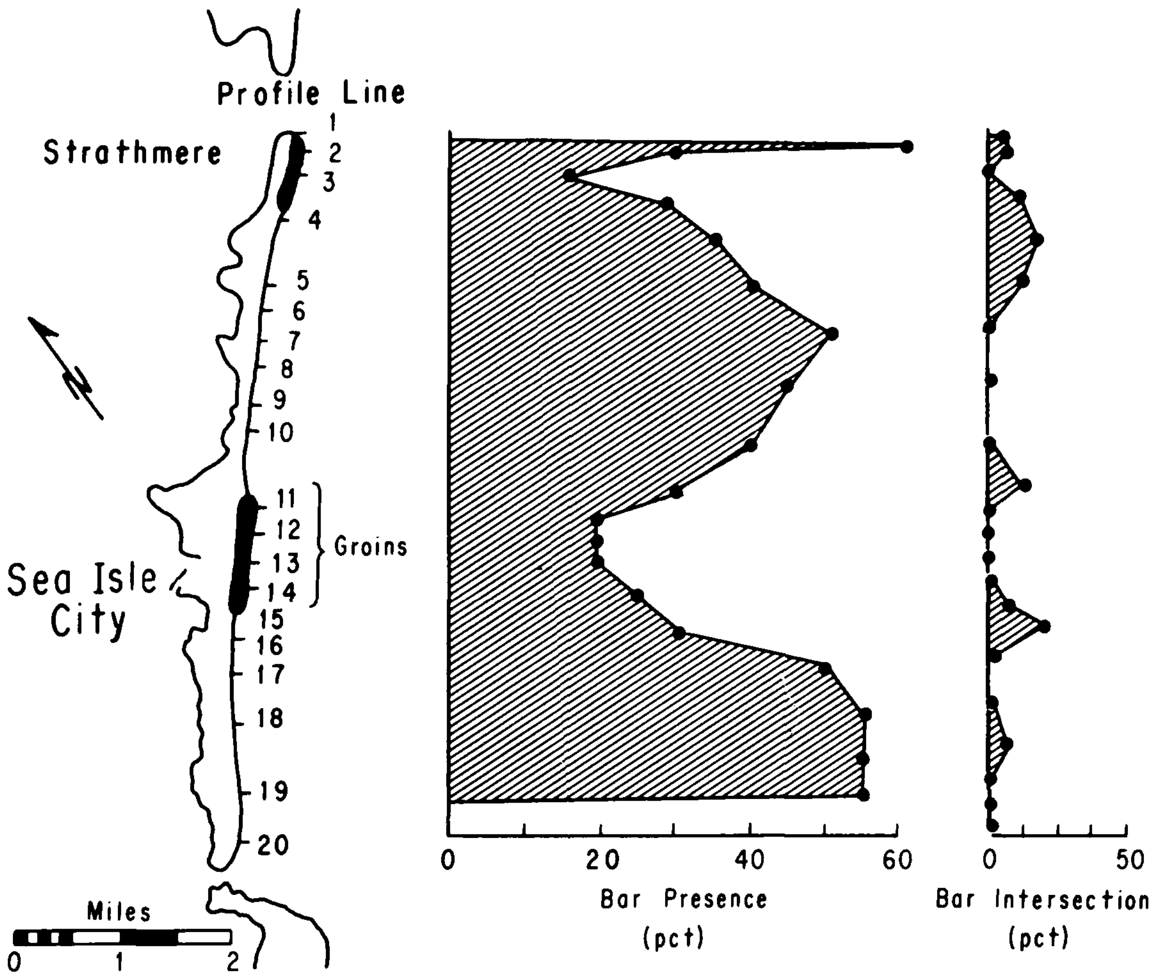

Figure 48. Percent of time submarine bars were present in aerial photos and the percent of time a submarine bar was observed to intersect the coast of Ludlam Beach. Note the decreased bar presence along the Sea Isle City groin system reach of the coast.

locations on the aerial photos is shown in Figure 49. Ridge-and-runnel systems were most frequent in the indentations north and south of Sea Isle City.

The average distance of the bars from the shoreline (waterline) is shown in Figure 50. This distance varied between 375 and 850 feet, and averaged about 500 feet. In most cases only a single submarine bar was observed.

It cannot be assumed that wave energy reaching the coast is uniform the length of the barrier island, nor that wave approach direction is constant at the coast. An analysis of the aerial photos, primarily on wave approach direction on submarine bars and on the beach, provided information on the alongshore variation in these parameters. The information is only on relative variations in wave direction and not on the distribution of wave approach angle for a specific location on the beach.

Wave approach angle, at breaking, was measured on the submarine bars and on the beach (Fig. 51). For the same sets of deepwater waves, such illustrations

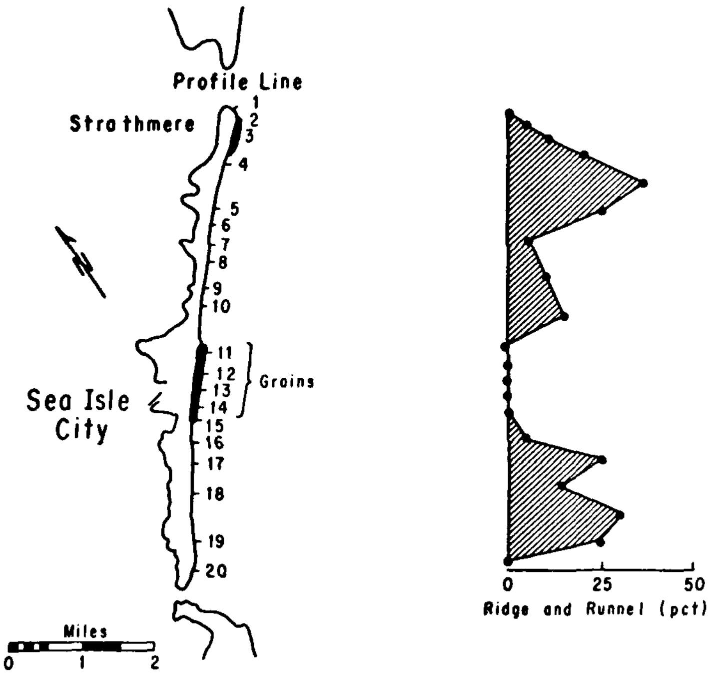

Figure 49. Percent of time a ridge-and-runnel system was present in aerial photos.

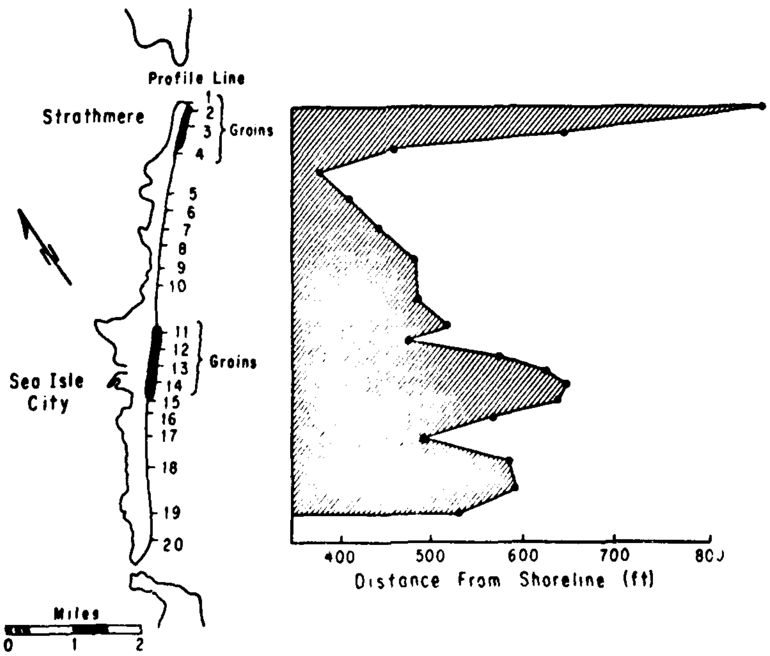

Figure 50. Average distance from the shoreline to submarine bars on Ludlam Beach.

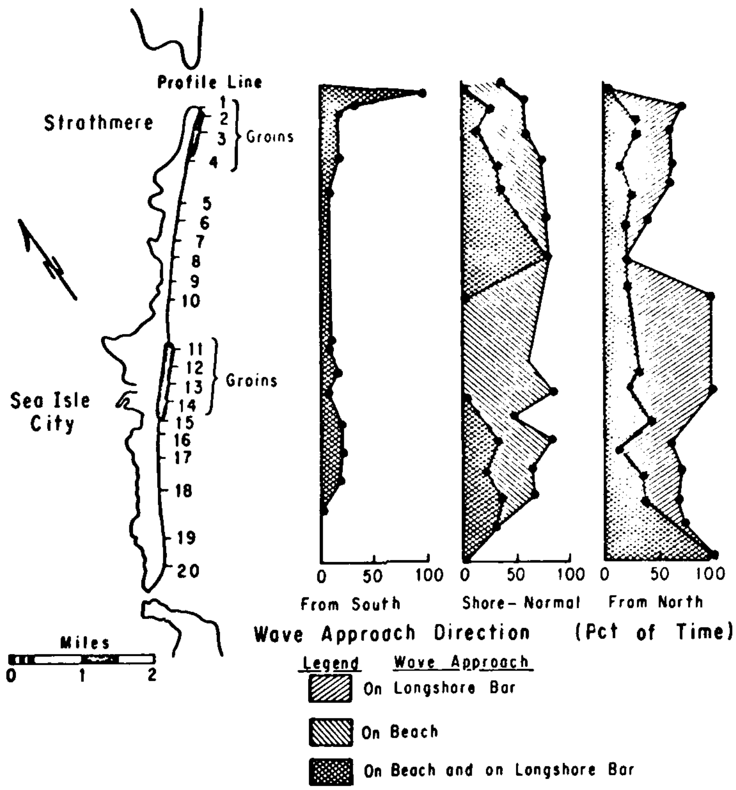

Figure 51. Wave approach direction on longshore bars and on the beach, obtained from an analysis of the 20 aerial photo sets of Ludlam Beach. Note the greater part of the waves which are oriented north of shore normal where they break on the longshore bars.

may provide qualitative information on longshore transport variability. As noted previously, they mostly represent conditions which existed each spring.

9. Outcrops of Organics.

Highly compacted organic material, often including silt- and mud-sized inorganic particles, was frequently observed outcropping on Ludlam Beach. These outcrops were usually exposed in the coastal indentation between the southernmost Strathmere groin and the northern part of the Sea Isle City groin system (Fig. 52).

An analysis to determine the location of such outcrops was made using aerial photos obtained on 8 March 1962 during the waning stages of the 6 to 8 March storm. This date was selected because the shoreline position analysis indicated the coast had retreated a large amount in a short time as a result of the storm. Thus, the exposure of outcropping organics was probably greatest at that time. Aerial photos taken on other dates exhibited considerably less exposure of organics.

Figure 52. Peat exposure at profile line 5, 22 December 1977.

Figures 2 and 3 show the location of peat exposures on 8 March 1962. In some instances the exposures were more than 100 feet wide. Field observations of the organic outcrops indicated thickness varied from 1 to 3 feet.

10. Inlet Changes.

Corson and Townsend Inlets experienced significant mean changes in shoreline, channel position and orientation, and ebb tidal bar location between 1949 and 1974. An analysis of aerial photos was the only available means of detailing those changes.

Hydraulic information on Corson and Townsend Inlets is very limited; e.g., only one set of hydraulic measurements has been reported and that was in 1957 for Townsend Inlet (Jarrett, 1976). At that time the diurnal tidal prism was 3.6×10^{8} cubic feet and the inlet hydraulic radius was 18.8 feet. However, inlet conditions have changed considerably since then.

The 20 sets of aerial photos taken at low tide were analyzed for changes in inlet characteristics. The following are the results:

a. Shoreline Changes. Changes in shoreline shape and position during the period 1949 to 1974 are illustrated in Figures 53 and 54. The dashline represents the 1949 shoreline position.

b. Inlet Width. As shown in Figure 55, the minimum inlet widths varied considerably in what appear to be long-term trends. From 1949 to 1974 the width of Townsend Inlet decreased almost 50 percent (from 900 to 500 feet); the width of Corson Inlet expanded, increasing almost six times the size in 1949 (400 to 2,300 feet).

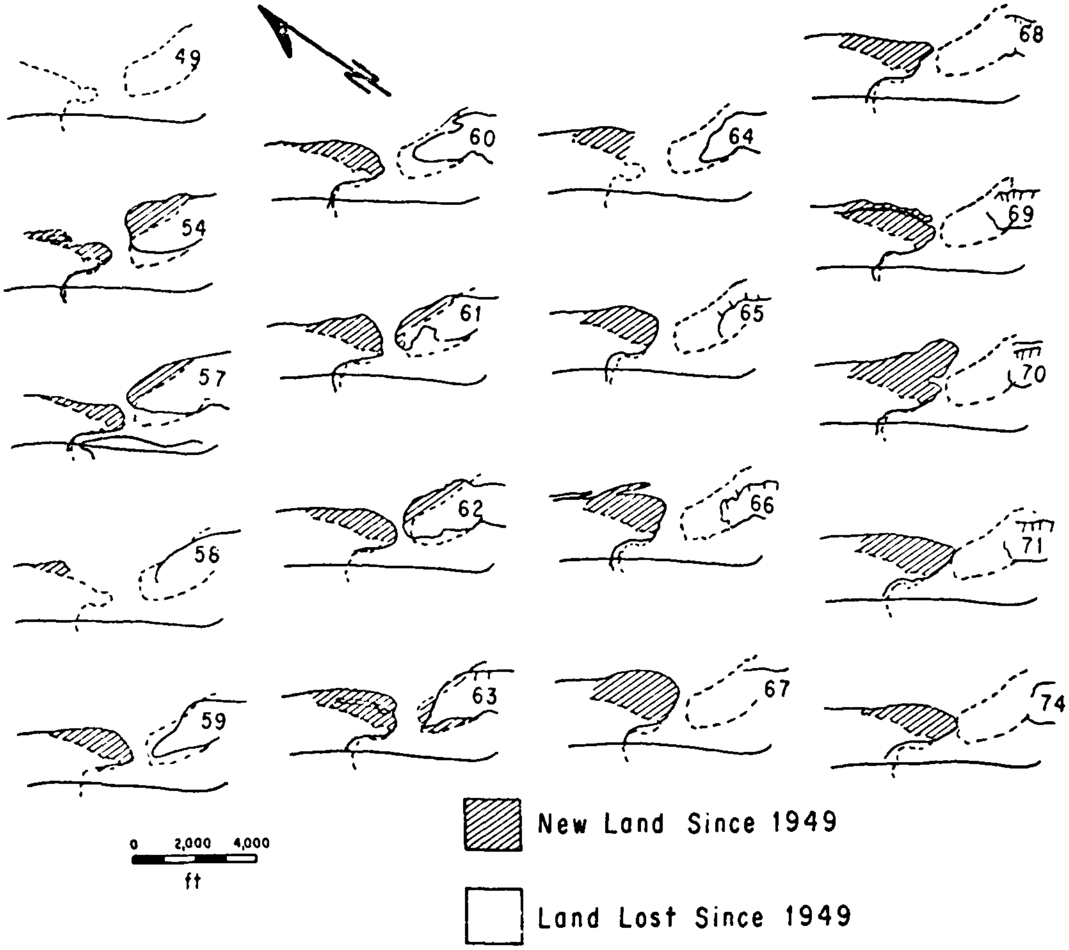

Figure 53. Shoreline changes near Corson Inlet (obtained from aerial photos). Dashline is 1949 shoreline.

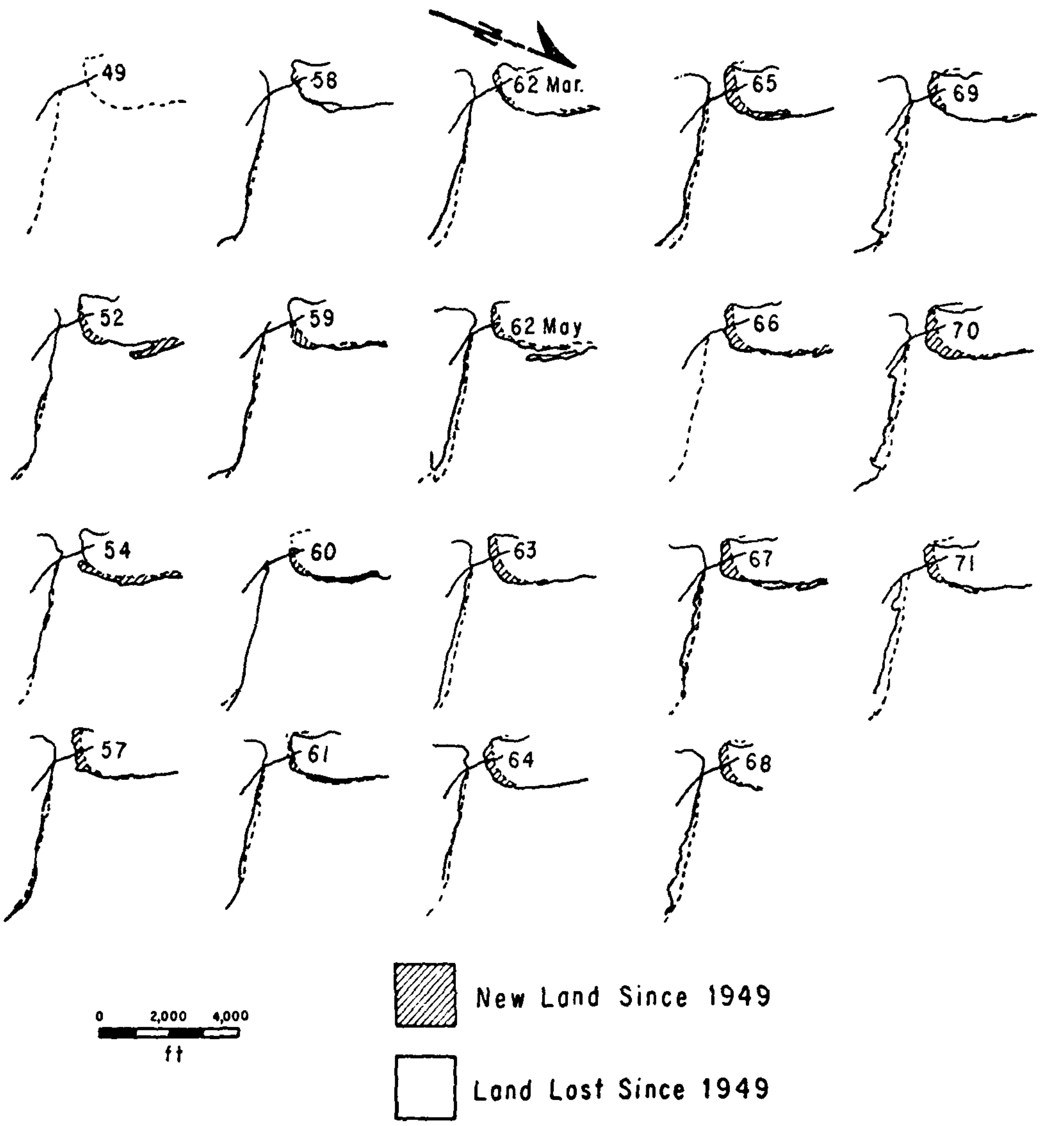

Figure 54. Shoreline changes near Townsend Inlet (obtained from aerial photos). Dashline is 1949 shoreline.

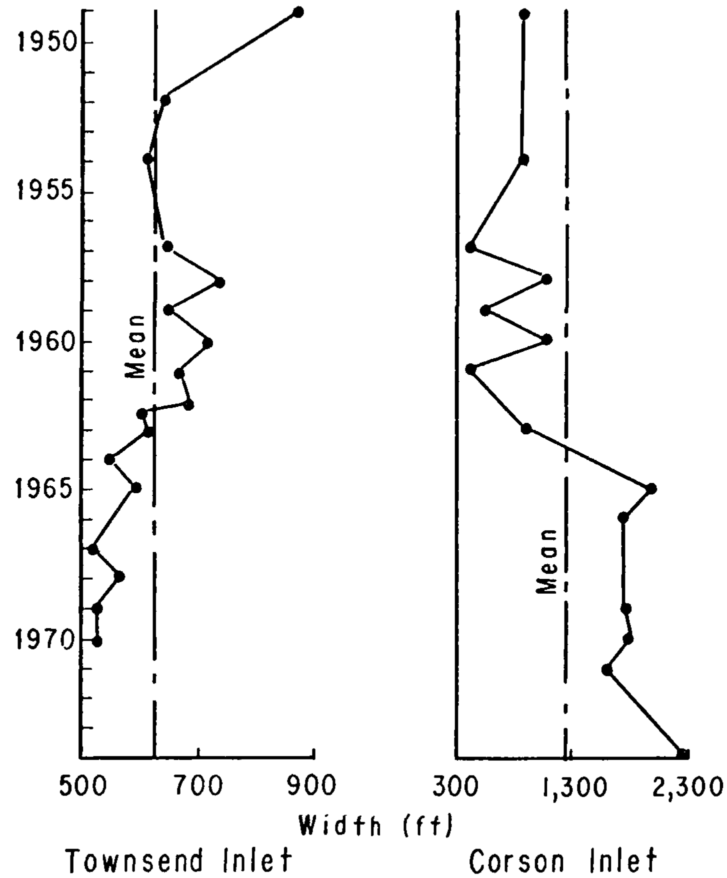

Figure 55. Minimum inlet width, Townsend and Corson Inlets, measured at the narrowest throat position. Note change in horizontal scale.

c. Inlet Throat Migration. The inlet throats varied not only in width, but also varied in location. Figure 56 illustrates the migration of the two inlets north and south along the coast. The north-to-south migration rates from 1949 to 1974 were 92 and 9 feet per year for Corson Inlet and Townsend Inlet, respectively.

d. Inlet Offset. Figure 57 illustrates an inlet offset parameter obtained from the aerial photos. It is essentially an offset of the shore near the inlet, i.e., the spit offset, and not the entire island offset. Offsets were obtained by measuring 500 feet north and south of the barrier island shorelines along a fixed base line on all photos. The centerpoint of the island width normal to the base line was then obtained and the offset of the two centerpoints about the north-south base line was measured.

e. Channel Position. Channel position in Townsend and Corson Inlets is given in Figure 58. Values of less than one indicate the channel was near the north shore, such as occurred for the last 10 years at Corson Inlet. Values greater than one indicate the channel was near the south shore, i.e., 1949-62 at Corson Inlet. Values near unity at Townsend Inlet mean the channel was midway between the bounding island shorelines.

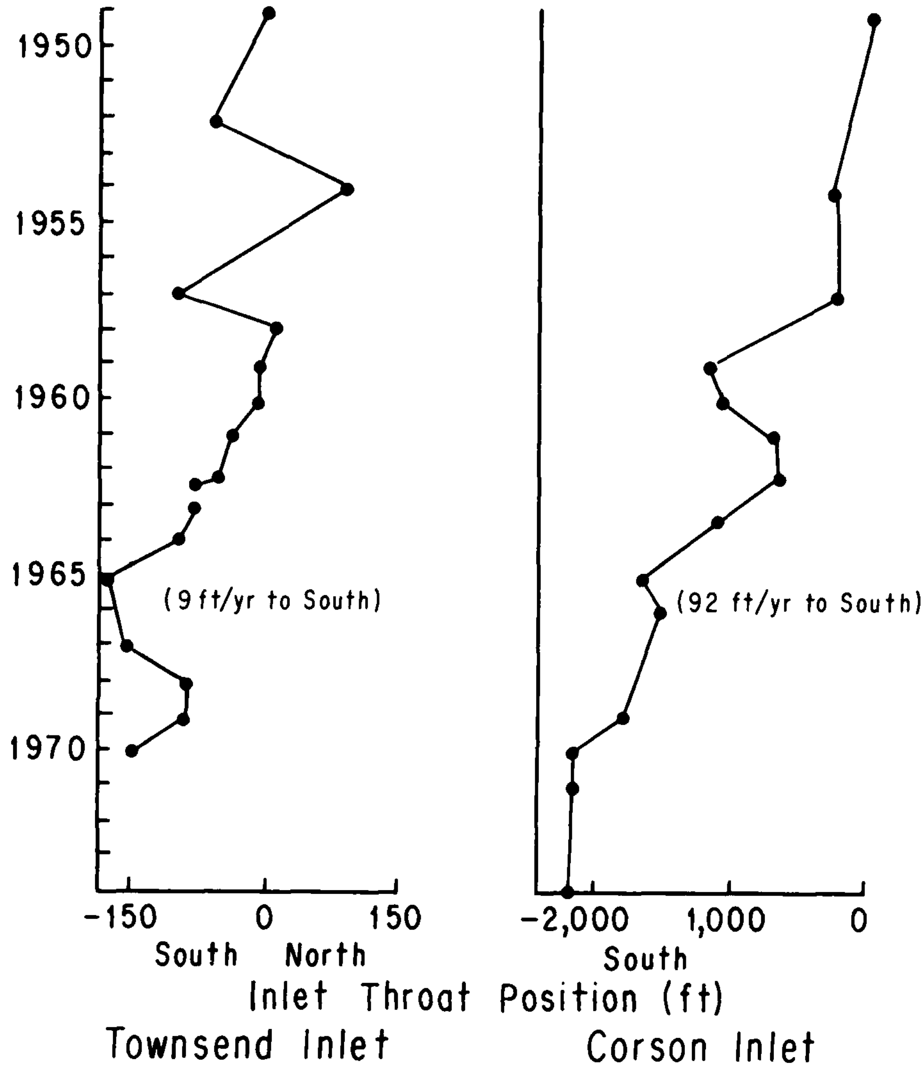

Figure 56. Inlet throat migration at Townsend and Corson Inlets, north or south along a fixed base line oriented approximately north-south across the narrowest throat section in 1949. A trend of large to small value indicates throat migration to the south. Note change in horizontal scale.

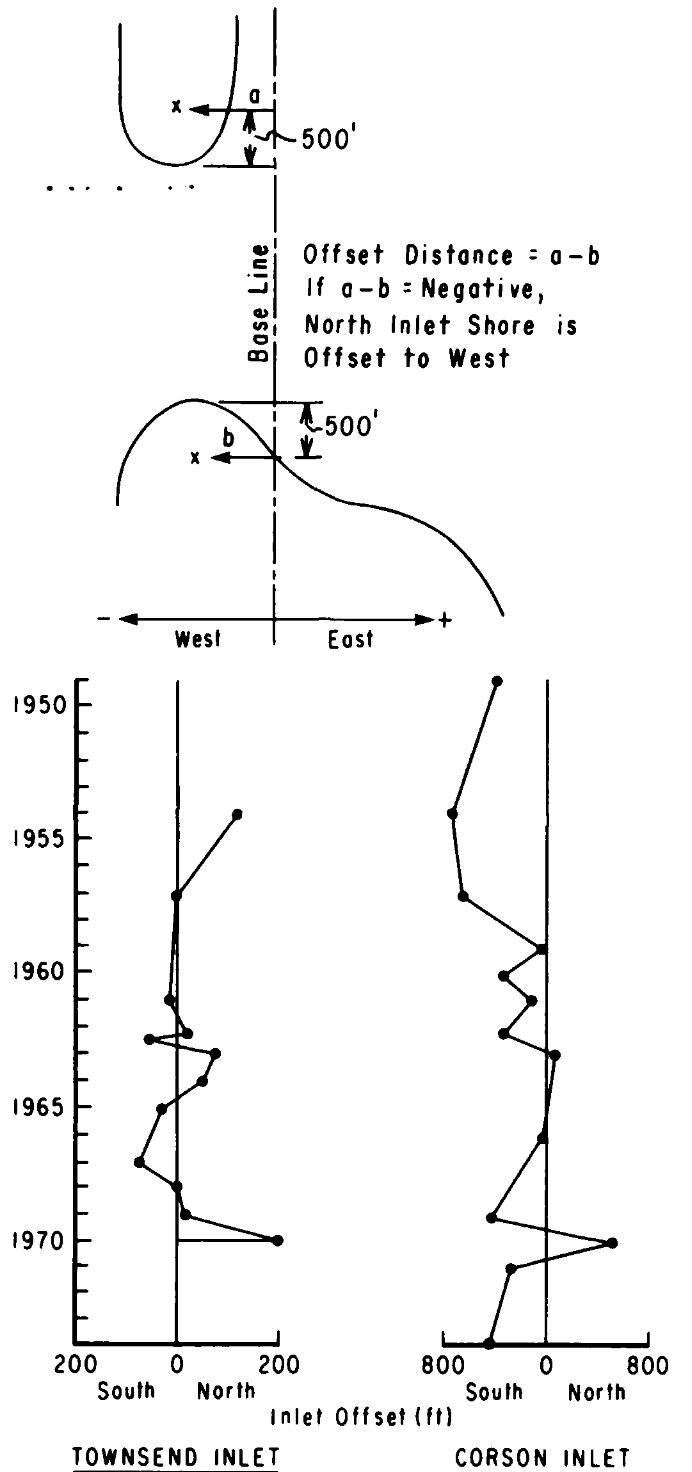

Figure 57. Seaward offset of inlet shoreline as obtained from aerial photos. North indicates island shoreline 500 feet north of the inlet is offset in a seaward direction.

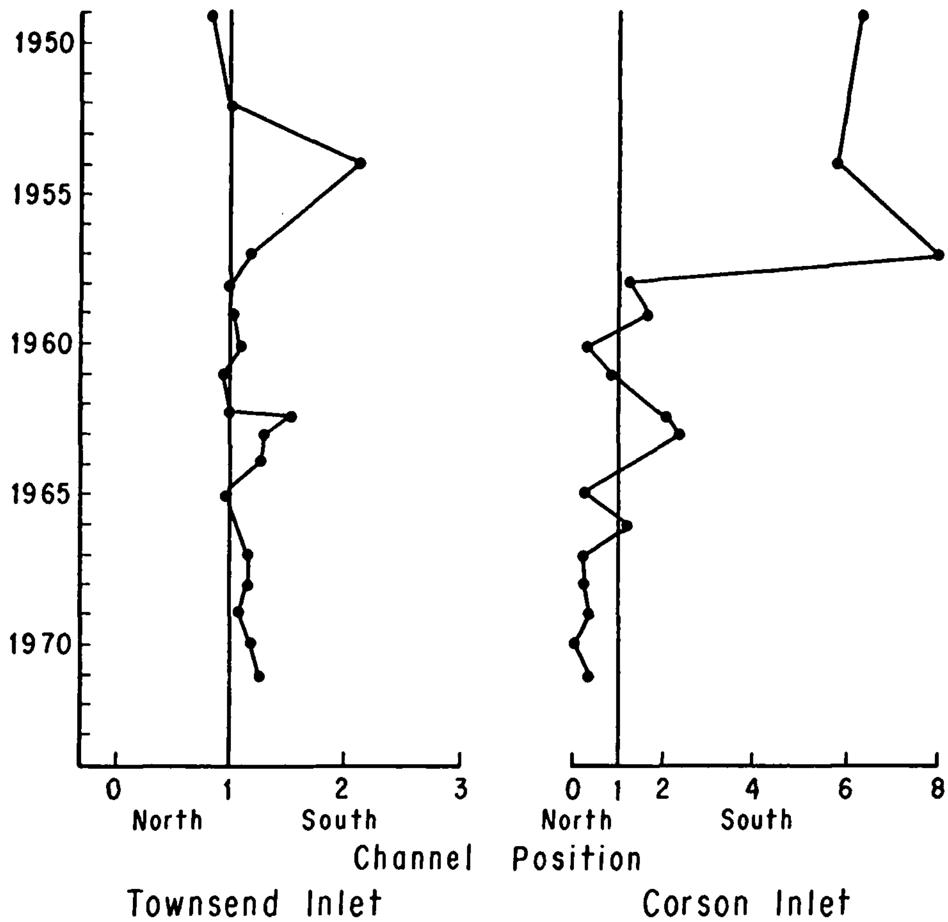

Figure 58. Channel position at Townsend and Corson Inlets. Values less than one indicate the channel is near the north shore. Values greater than one indicate the channel is nearer the south shore. Values are the ratio: distance north shore to channel center/ distance south shore to channel center. Measurements were made in the inlet throat.

f. Channel Orientation. Channel orientation seaward of the inlet throat changed very little between 1949 and 1974 at Townsend Inlet; however, the orientation of the channel at Corson Inlet appeared to vary consistently (Fig. 59).

g. Channel Length. Figure 60 shows the channel length at Corson Inlet. Length is distance from the center of the inlet throat to where the channel passes through the seawardmost line of breaking waves.

h. Plan Area of Offshore Bars. Figure 61 is the plan area of visible shoals seaward of the inlet throats at Corson and Townsend Inlets, measured by a planimeter. Both visible shoals and shoals inferred from breaking wave patterns were included.

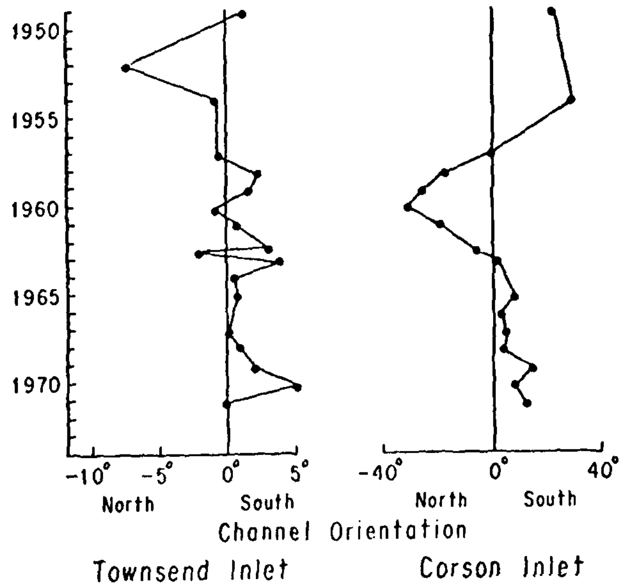

Figure 59. Variation in channel orientation seaward of the barrier islands. Low values indicate an orientation toward the north, high values a more southerly orientation. Note the horizontal scale varies between Corson and Townsend Inlets.

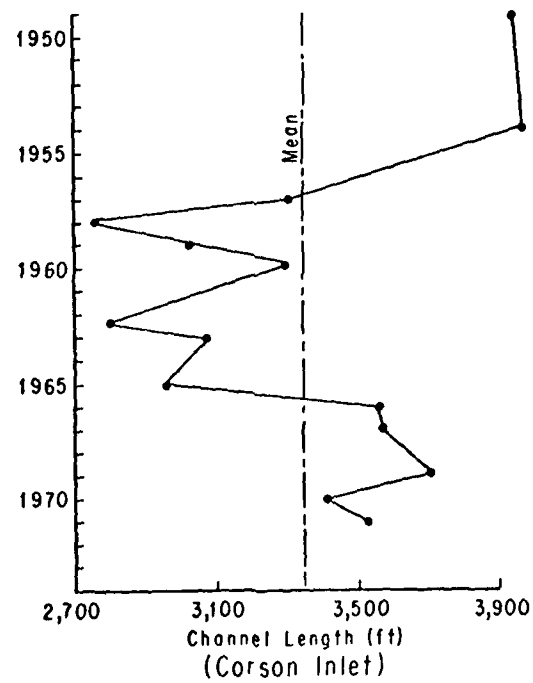

Figure 60. Channel length from center of inlet throat to seawardmost breaking wave line on ebb tidal shoals.

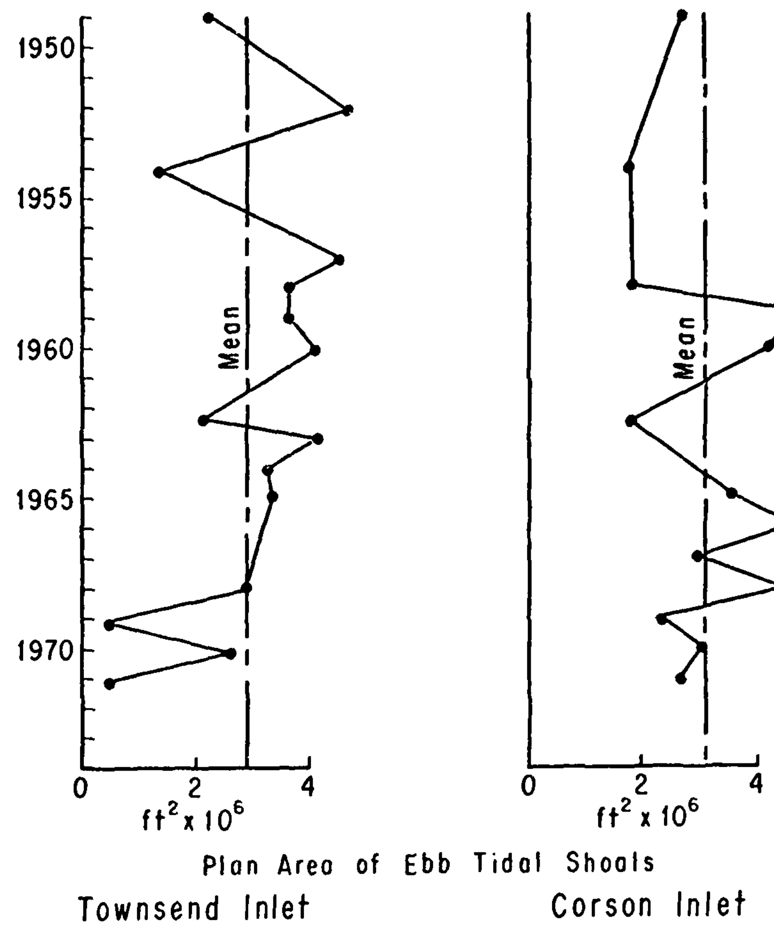

Figure 61. Plan area of visible ebb tidal shoals (seaward of inlet throat) as obtained from aerial photos.

i. Plan Area of Island Ends. Cumulative changes, between 1949 and 1974, in the land area above MSL are shown for Corson Inlet in Figure 62. The land area surrounding Corson Inlet has consistently changed. Between 1949 and 1974, the north shore of the inlet gained an average 0.006 square mile per year while the south shore lost 0.007 square mile per year. The north shore of Townsend Inlet gained 0.0001 square mile per year.

V. IMPLICATIONS FOR COASTAL PROCESSES

Data collected during this study provide an insight into the behavior of the Ludlam Beach coastline and the processes affecting changes in the coastline.

1. Beach Shape.

As the Ludlam Beach shoreline generally retreated (Fig. 38), the beach maintained its characteristic width and foreshore slope (Figs. 22 to 26). The long-term implication of this condition is that as the shoreline moved in a westerly direction, the beach retained its shape and moved with it. Thus, the

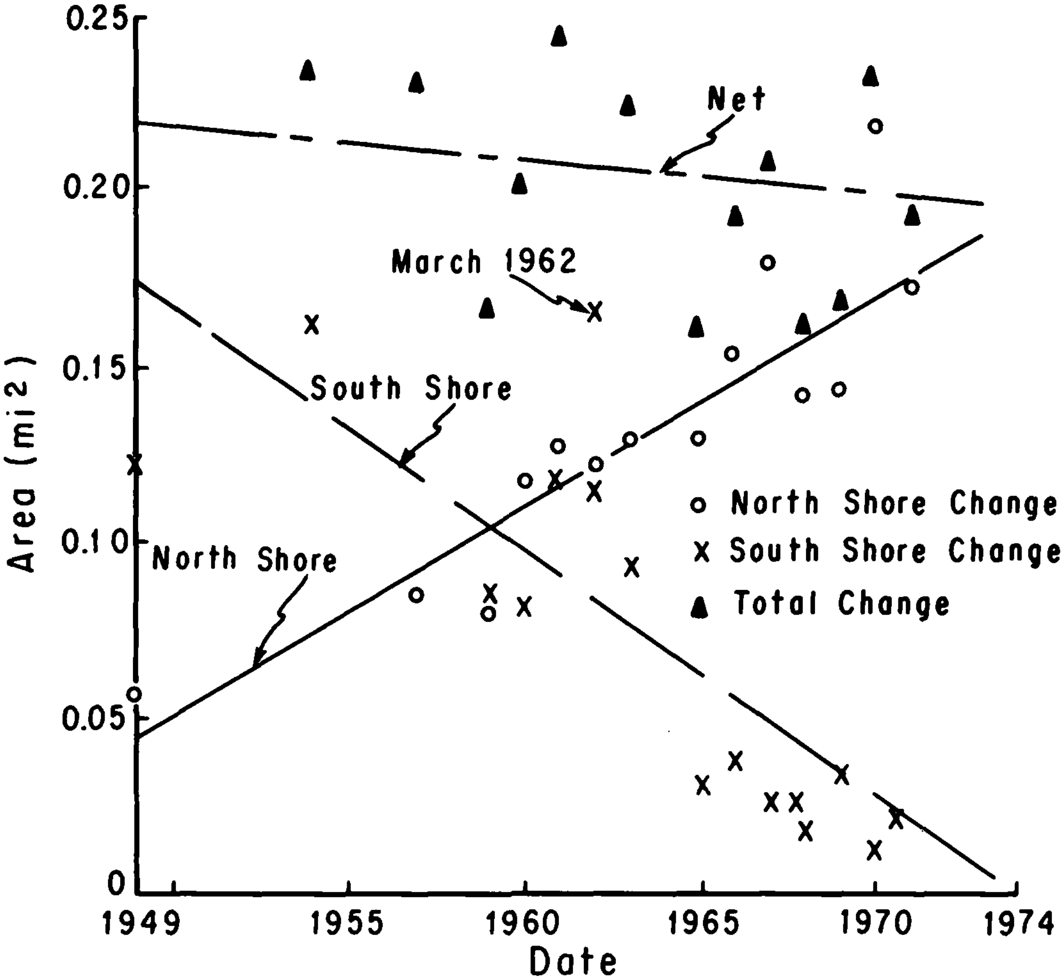

Figure 62. Cumulative land area changes (above MSL) at Corson Inlet, 1949-74.

recreational potential of the beach was not decreased, but there was a loss of valuable coastal property landward of the beach. Fixed manmade structures such as roads, parking lots, and buildings were also jeopardized.

2. Alongshore Sand Movement.

a. Longshore Transport Analysis. The following analysis utilizes wave height data (averaged by month) and a constant wave period obtained from a gage in Atlantic City (Fig. 15), and wave direction data from visual observations near Sea Isle City (Fig. 17). These data were applied in an analysis using the energy flux method (U.S. Army, Corps of Engineers, Coastal Engineering Research Center, 1977).

Wave power, $\overline{P}$, reaching the beach (see Fig. 8) was obtained using the equation

$$\overline{P} = \frac{\gamma \, C t_g H^2}{8} \qquad (2)$$

where

$\overline{P}$ = wave power in foot-pounds per foot of beach per t_g

t_g = time interval equal to 1 month

γ = water density at 64 pounds per cubic foot in saltwater

C = wave group velocity in feet per second in shallow water, where the acceleration of gravity is 32.2 feet per second squared, and water depth is 18 feet

H = wave height in feet

To compute wave approach angle, using the sector method (Fig. 17), the observed approach angles were assumed to be normally distributed within each of five sectors. Thus, the frequency distribution of wave approach angle in sector 2 was assumed to be identical to that in sector 4 even though the total number of observations in sector 2 was larger. If a skewed distribution were used, based on the number of observations, the net longshore transport rate to the south would be larger than that calculated. About 58 percent of all observations were in sector 3, within 5° of shore normal.

The longshore component of wave power, P_ℓ, was computed using equation (4-27) in the Shore Protection Manual (SPM) (U.S. Army, Corps of Engineers, Coastal Engineering Research Center, 1977, p. 4-91):

$$P_\ell = \overline{P} \cos \alpha \sin \alpha \tag{3}$$

in which α = angle between a line normal to the shore and the wave orthogonal at the breakpoint. They were obtained using the relation (U.S. Army, Corps of Engineers, Coastal Engineering Research Center, 1977, p. 4-100)

$$Q = (7.5 \times 10^3)\ P_\ell \tag{4}$$

in which Q = longshore transport rate. The resulting north and south longshore transport rates (the monthly gross and net rates) are shown in Figure 63. Absolute values at Sea Isle City (profile line 14, where wave angle measurements were made) in thousands of cubic yards per year, are:

North	South	Gross	Net
357	786	1,143	429 south

These longshore transport rates are considerably different from those previously reported for Ludlam Beach. Caldwell (1966) noted a rate of 200,000 cubic yards per year to the south at the Cold Spring Inlet jetty (20 miles south of Ludlam Beach) and a rate of 100,000 cubic yards per year at the Absecon Inlet jetty (20 miles north of Ludlam Beach). He indicated that the inlets act as traps for sandy material moving along the coast and the amount of material stored in the inlets becomes a constant quantity as the inlet reaches a stable cross-sectional area. He believed that "excessive" sand trapping was occurring as evidenced by the large floodtide shoals and by the fact that losses from the shore were considerably in excess of the measured longshore transport rates.

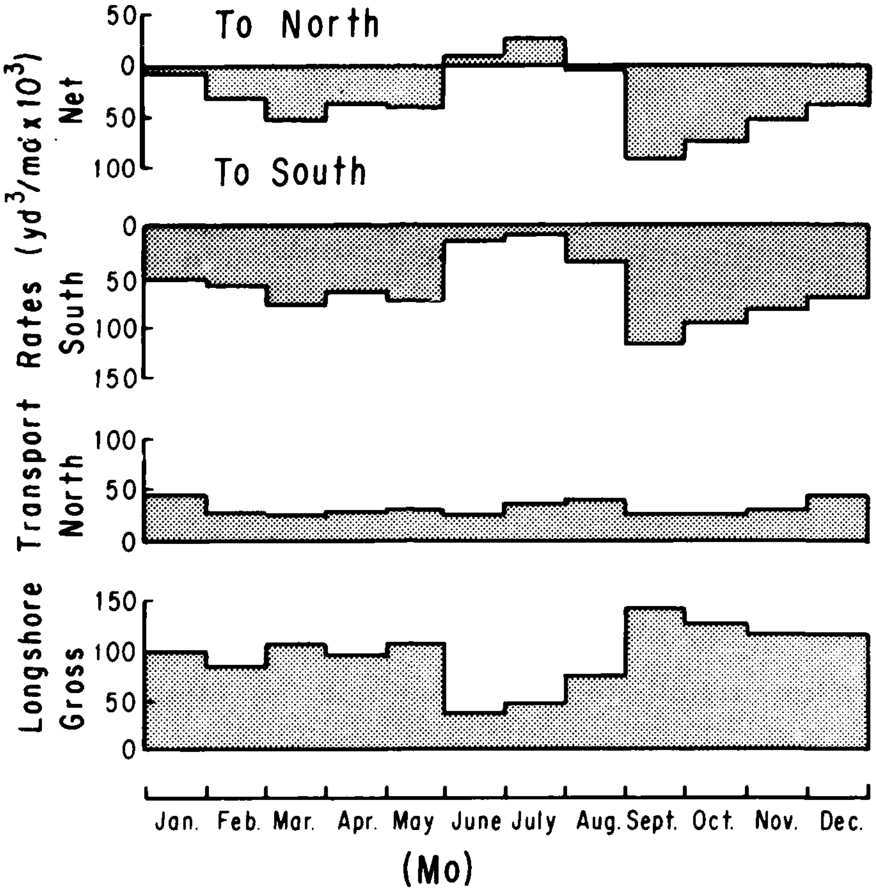

Figure 63. Gross and net longshore transport rates at Sea Isle City, obtained using the energy flux method.

Caldwell presented the following longshore transport values for Sea Isle City in thousands of cubic yards per year:

North	South	Gross	Net
500	650	1,150	150 south

Caldwell's net rate to the south is only 35 percent of the rate from this study. This may be the result of using equation (4) in this analysis which is 83 percent higher than that previously recommended (U.S. Army, Corps of Engineers, 1966).

b. Alongshore Sand Movement Above MSL. From 1962 to 1972 the beach surveys indicated the movement of a sand mass (sand wave or hump) alongshore. On individual profile lines (Fig. 41) the net volume change above MSL, averaged yearly to remove seasonal effects, and the net yearly shoreline change (Fig. 40) followed definite trends through time. Periods of shoreline advance alternated with periods of shoreline retreat, and volume maximums alternated with volume minimums. Adjacent lines showed cyclicity with a slight phase change, resulting in what appeared to be the north to south movement of a sand wave. Movement to the south was directly related to the direction anticipated using wave data (Fig. 63). The migration rate of the sand wave averaged 5 feet per day to the south. The time interval from a year of maximum loss (dashline, Fig. 41) to the next maximum yearly loss at the same location was 10 or 11 years near the center of Ludlam Beach. Since only one sequence was monitored it is unknown whether this was a constant period, whether it varied, or whether the sand waves were intermittent features produced by unique events.

Between locations of maximum yearly loss the alongshore distance between wave crests was 16,500 feet when the midpoint was 10,000 feet south of Corson Inlet, and 13,000 feet when midpoint was centered 18,000 feet south of the inlet. The apparent decrease in wavelength may have been caused by either a slowing of the travel rate of a trough or by an acceleration of the sand-wave crest movement. It may also have been due, in part, to a steady loss of volume as the sand wave progressed south. The average wavelength is about 16,000 feet, about one-half the length of Ludlam Beach. The wavelength apparently decreased about 2.5 percent per 1,000 feet as the sand wave moved in a southerly direction.

At Corson Inlet the volume difference of the sand wave, from minimum to maximum, was 46 cubic yards per foot, which decreased to an average of 15 cubic yards per foot at profile line 3. From profile line 3 south to the Sea Isle City groins the amplitude remained constant. Farther south the amplitude appeared to be affected by the groins. The total volume under the sand wave, assuming a wavelength of 16,000 feet and a maximum volume of 15 cubic yards per foot, was 240,000 cubic yards above MSL. Assuming the sand wave moves southward, and that beach sand moves the same rate as the sand wave, the volume in the sand wave moving alongshore would be as shown in Figure 64. A rapid decrease in volume occurred away from Corson Inlet then slowly declined to the north of the Sea Isle City groin field where the volume increased 25 percent. Because the coastal orientation changes rapidly near Corson Inlet, some of the loss between profile lines 1 and 2 possibly resulted in permanent losses to the offshore zone.

This study produced no results to substantiate the assumption that beach sand moves alongshore at the same rate that the sand wave moves. However, if the alongshore movement of the sand wave represented an alongshore movement of sand above MSL, the average net alongshore sand transport rate near the center of the island would be about 40,000 cubic yards per year. In a study similar to the present study, Everts, DeWall, and Czerniak (1974) found the volume of a sand wave moving above MSL along the northern one-half of Absecon Island, about 30 miles north of Ludlam Beach, was 30,000 to 34,000 cubic yards per year in 1964-65.

An important problem in predicting this type of sand wave is determining its cause. One possible cause at initiation near Corson Inlet was a large noncyclic input of sediment to the north end of the beach. Such a catastrophic input could result from sediment movement during a severe storm. Bruun (1966), for example, noted that the channel at Matanzas Inlet, Florida, moves slowly from north to south in the direction of predominantly littoral drift. When it is in an extreme southern position and a severe northeast storm occurs, the channel breaks through the ebb shoal on the north side of the inlet, the south

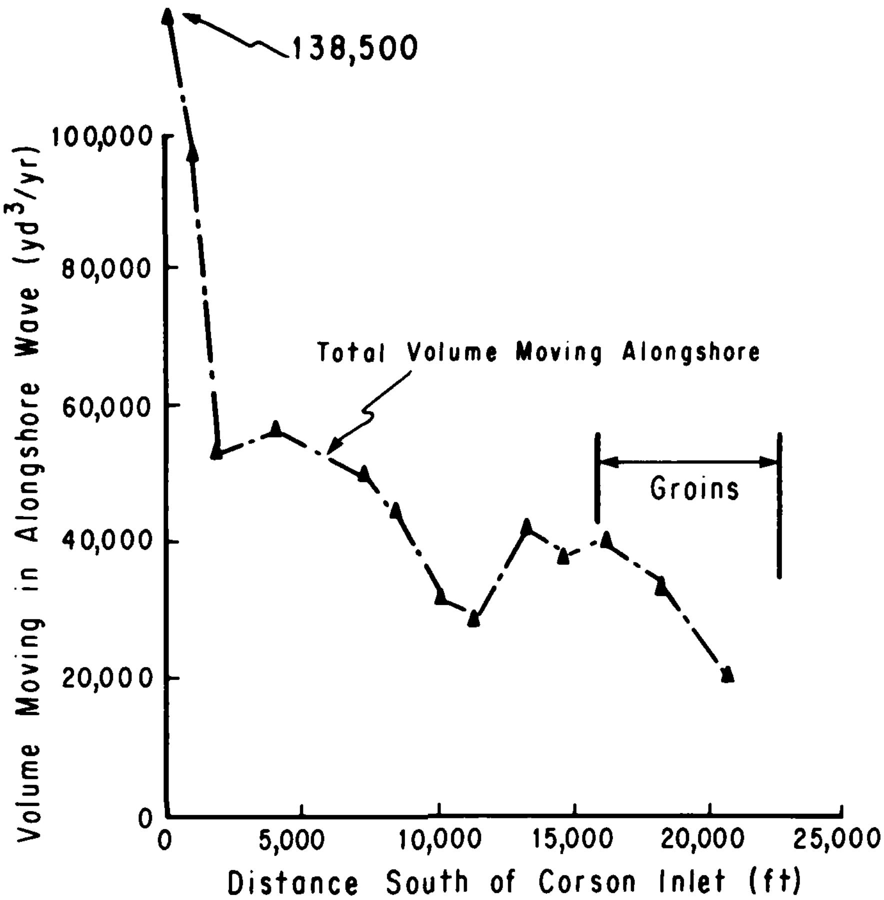

Figure 64. Volume moving in an alongshore sand wave, showing a significant decrease south of Corson Inlet.

shoal closes, and a large quantity of material is transferred at one time to the downdrift barrier island. Bruun states this rapid accumulation substitutes several years of downdrift accumulation by normal inlet sand-bypassing processes.

The March 1962 storm could have caused such an accumulation at Strathmere. As shown in Figure 62, about 0.05 square mile of new land was created at the south shore of Corson Inlet in March 1962. This change, which amounts to 186,000 cubic yards of accretion above MSL when assuming a 3.6-foot land elevation (Fig. 17, berm elevation), is opposite of the general trend of a net loss of land south of the inlet. In 1962, land-area gains north of the inlet were average but the inlet shoal area (Fig. 62) decreased significantly, suggesting a source there. The movement of the channel during the storm (Figs. 55, 56, 58, 59, and 60) did not appear to occur as at Matanzas Inlet.

c. Alongshore Variation in Sediment Transport. It cannot be assumed that wave energy reaching the coast is uniform the length of Ludlam Beach, nor that the wave approach direction is constant along the coast. Information on wave approach direction is available, based on aerial photo analyses. Wave approach direction at breaking for 20 synoptic times along the beach is given in Figure 51. The figure mostly represents conditions in the spring and statistically cannot be indicative of the average yearly condition of wave approach direction.

However, the following inferences are drawn from the figure:

(a) Waves from the north are much more pronounced (averaging more than 70 percent of all waves) on Ludlam Beach submarine bars than on the beaches, suggesting a greater longshore transport on the bars for a given expended wave energy.

(b) Based on a dominance of waves approaching and breaking on the beach or bars from the south, even when deepwater waves approach from the north, a nodal point appears to be at the north end of the island. At the nodal point, waves approaching from the south dominate north of the point, and waves from the north dominate south of the point. This is probably the result of refraction as waves pass over the ebb shoals seaward of Corson Inlet. On Ludlam Beach in 1974, the nodal point occurred about 1,500 feet south of Corson Inlet.

(c) In the central and south parts of the island, the relative percentage of each wave approach direction appears similar, and longshore transport rates do not vary greatly from place to place.

(d) Most of the aerial photos were taken in the spring when submarine bars are most abundant and pronounced. This is the season when the least amount of sand is in storage on the subaerial beach and the offshore sand volume is the largest. Thus, sediment movement alongshore on the bars rather than on the beach is probably most pronounced in late spring and least in the fall.

(e) Submarine bars are present about 40 percent of the time in the spring, and may be near-absent in the fall. Therefore, bar transport in 1 year probably occurs an average 20 percent of the time.

(f) The height of waves breaking on bars is probably larger than the height of those breaking closer to shore. Also, the wave approach angle, because of less refraction, is greater on the bars, suggesting a greater longshore component of sediment transport on the bars.

(g) The importance of longshore bar transport versus longshore beach transport is in determining where the material is moving, especially relative to coastal structures, such as groins, weir jetties, and weir basins.

(h) Submarine bars near inlets, especially on the south end of the New Jersey islands, flare seaward and join ebb tidal shoals at the inlets. This distance is considerably seaward of the usual position of weir sections in jetties.

3. Onshore and Offshore Sand Movement.

Sand movement from the beach to the offshore region, or from offshore onto the beach, involves storm, seasonal, and longer term exchanges of sand which may affect coastal stability and structures. Each type of exchange is difficult to predict analytically. Limited data on the amount and distance of sand movement are available and are discussed below.

a. Wave Effects. The most important factor in developing the geometry of a beach, and in the sand movement from or onto the beach, is the waves which act upon it. At Ludlam Beach there appears to be a direct temporal relationship between the relative volume of sand above MSL and the frequency of waves greater than 4 feet in height (see Fig. 16). Waves exceeding 4 feet at the Atlantic City gage were often associated with storms. The steepness (wave height/wavelength at the gage) of a 4-foot wave with an 8-second period is 0.022. This steepness value is assumed to designate the cutoff point between waves causing erosion and those causing accretion. However, caution is recommended when using this value. Saville and Watts (1969) for example, pointed out although bounding wave steepness values between 0.020 and 0.025 are commonly used, these values are derived mostly from laboratory studies and are of doubtful accuracy when applied to a field situation.

Monthly changes in sand volume are directly related to the monthly wave power reaching the beach, as shown in Figure 65. Beach volume changes are from Figure 33. Five years of wave data (1962-67) and 10 years of survey data (1962-72) were averaged to obtain Figure 65. The figure supports the assumption that waves with an 11-second period and less than 4 feet high cause beach accretion. For the North Sea coast, Schijf (1959) observed a relationship between winter gales and summer swell, and their effect on beaches, which was similar to the accretion-erosion changes observed at Ludlam Beach.

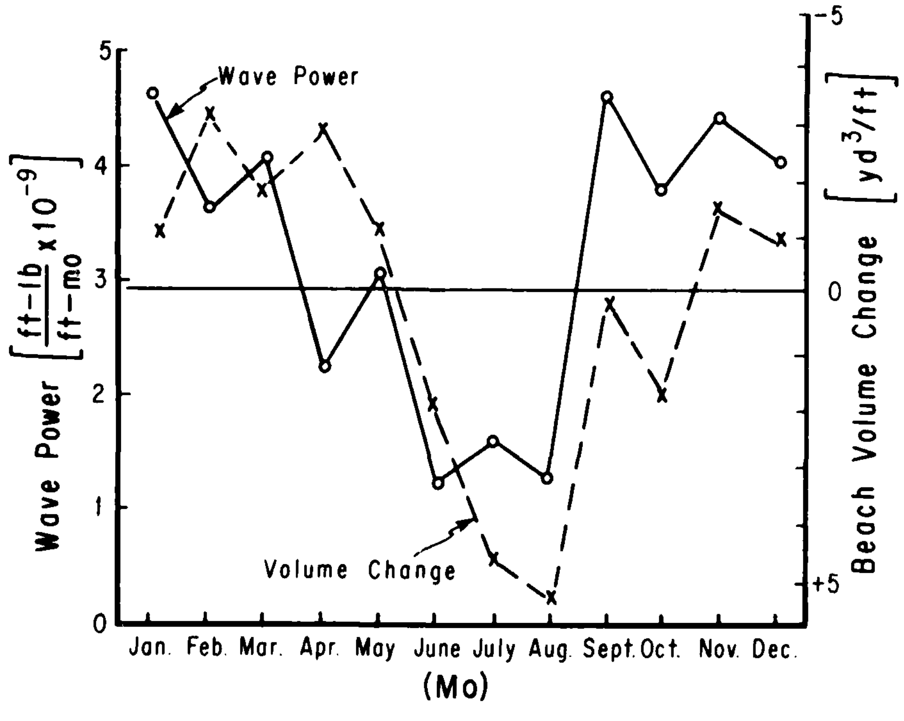

Figure 65. Monthly wave power of waves exceeding 4 feet in height reaching the Atlantic City shore, showing the relationship between wave power and beach volume change.

Yearly gains or losses of sand to the subaerial beach appear to be characterized, to some extent, by the number and severity of fall and winter storms. However, yearly wave power for waves exceeding 4 feet in height appears to be only partially related to yearly sand volume change as shown in Figure 66. Yearly wave power exceeding 2.8×10^{10} foot-pounds per foot-year is apparently sufficient to cause a net sand loss. The poor relationship between yearly wave power and yearly sand volume change is probably the result of insufficient data on specific storms which cause most of the net sand loss.

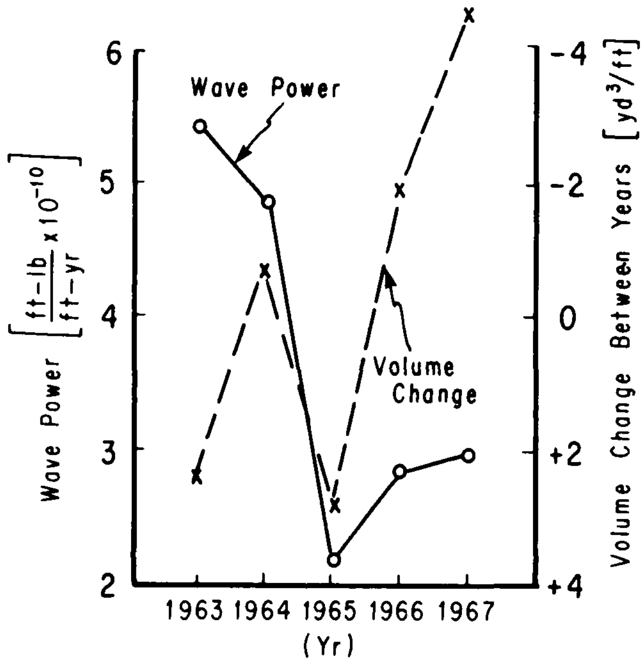

Figure 66. Yearly wave power for waves exceeding 4 feet in height at Atlantic City, showing the relationship between yearly wave power and yearly sand volume change above MSL.

Data from this study are insufficient to determine the effects of repetitive storms (Figs. 30 and 31). Survey data from the only successive storms recorded indicate a slightly lower loss of 1.5 cubic yards per foot of sand from the second storm (19 February 1972) than the first storm (4 February 1972) when 1.9 cubic yards per foot was lost. For the same storms on western Long Island, Everts (1973) calculated a loss of 5.1 and 6.7 cubic yards per foot for the first and second storms, respectively. Everts, DeWall, and Czerniak (1974) measured losses of 4.0 and 6.4 cubic yards per foot, respectively, for the two storms on the north coast of Absecon Island (Fig. 1). The two February storms were about equal in intensity and duration (Everts, 1973).

The shape of the cumulative sand volume plots (Fig. 35) was similar at all 20 profile lines and relatively consistent from year to year. Much of the average seasonal change (18 cubic yards per foot) must have been the result of onshore-offshore exchange. Such onshore-offshore movement has been observed at Ocean City, New Jersey (Watts, 1956); in Harrison County, Mississippi (Watts, 1958); at Virginia Beach, Virginia (Watts, 1959); and on a number of New England beaches (Perdikis, 1961). Both Watts and Perdikis found that material lost from the beach above MSL was transported directly offshore. They also found that subsequently most of the material was moved onshore again or moved in an alongshore direction.

The cyclic onshore-offshore movement to and from above MSL regions in a year's time (about 600,000 cubic yards) at Ludlam Beach is somewhat larger than the net alongshore movement (430,000 cubic yards per year). The importance of the net longshore movement is that it results in a permanent loss to the beach (usually replaced by sand entering the system from updrift sources). The onshore-offshore movement is cyclic and mostly temporary. Only about 40,000 cubic yards per year is permanently lost from Ludlam Beach.

For a loss or gain in sediment on a profile line, the material must move into or out of the region. Data from Ludlam Beach indicate the net yearly sand volume loss and, to some extent, the net yearly gain are related to the range of the onshore-offshore sediment volume exchange. Yearly range is the maximum mean monthly volume minus the minimum mean monthly volume of measured sand on the profile (Fig. 36). Figure 67 illustrates the relationship of net yearly sand loss and gain to yearly range.

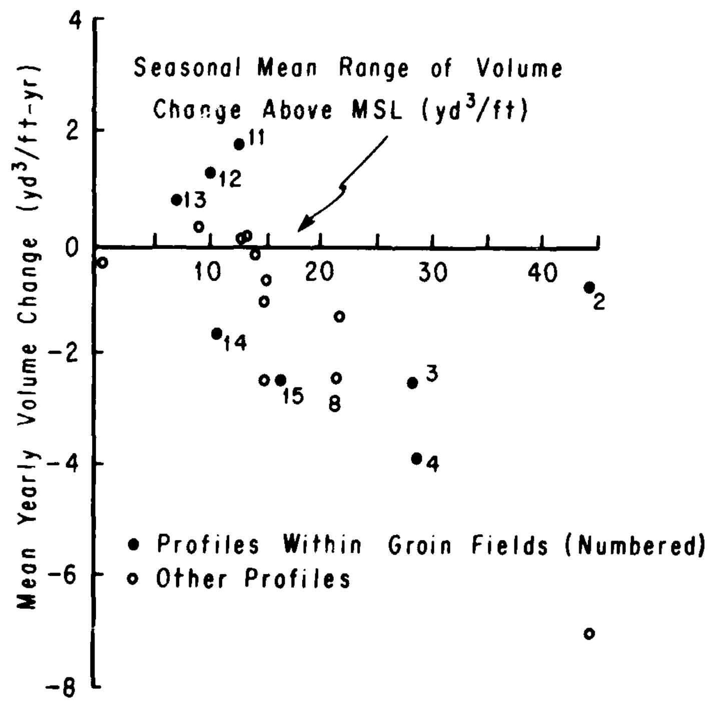

Figure 67. The relationship between the mean net yearly volume change (Fig. 32) and the seasonal range of sediment volume change (Fig. 29). As the range exceeds 12 cubic yards the net yearly volume loss increases.

As shown in the figure, the beach is stable when the yearly range is about 12 cubic yards per foot or less. There may be a yearly net loss of about 0.2 cubic yards per foot for each cubic yard per foot of yearly range above 12 cubic yards per foot. Thus, where the seasonal onshore-offshore exchange shown in Figure 36 exceeds 12 cubic yards per foot, there is a net loss of about 20 percent of the sand. This sand loss apparently results from movement off the profile above MSL in the fall through spring, with a lower replacement volume returning during the summer.

The volume of sand in storage above MSL and the shape of the beach profile appear to be significant factors in the amount of erosion or accretion occuring on a beach. For example, after a beach has been subject to low and moderate wave conditions for a considerable period, such as in late summer, a berm forms, the foreshore steepens, and the sand volume increases (Fig. 33). This volume then serves as a source for the sand eroded during fall and winter storms. The steeper storm-produced waves plane the berm off and create a very gradual foreshore. The resulting profile shape is then closer to equilibrium with the steep waves than the summer profile is.

b. Submarine Bars. Submarine bars are important because they are sources and later sinks in the seasonal movement of sand off and on the subaerial beach. Submarine bars are also an important longshore transport path. In designing structures to intercept alongshore sand movement, the presence of submarine bars, their position relative to shore, and the volume moved along them must be considered. Figures 47 to 51 show the following submarine bar conditions, with respect to coastal processes:

(a) Bars frequently began at the shore in the north and extended downcoast at a slight angle seaward of the coast. The cause of this nonparallelism may have been a more rapid movement of the bars at their northern ends as they migrated landward, or possibly the initial formation of the bars was closer to shore in the north.

(b) Bars appeared to intercept the coast in specified regions which include areas just downdrift of groin systems where ridge-and-runnel systems are most common.

(c) Bars are less pronounced off groin fields.

(d) Bars tend to angle in a greater seaward direction near groin fields than elsewhere.

VI. IMPLICATIONS FOR COASTAL ENGINEERING

1. Beach Fill.

Should a beach fill be planned on Ludlam Beach, the results of this study would provide a useful background on the historical behavior of the beach. Data are available on where erosion has occurred in the past and where it might be expected in the future (Figs. 27, 29, and 39). The regions at the Corson Inlet end of the island and in the indentations north and south of the Sea Isle City groins are unstable. Under present conditions, artifically placed fill material or possibly protective structures will be required to halt shoreline retreat in these unstable areas (net -8.2 feet per year).

Two general procedures for artificial beach restoration and improvement are stockpiling and direct placement (Hall and Watts, 1957). Stockpiling is the establishment and periodic nourishment of a volume of suitable beach material at the updrift sector of a problem area. Direct placement is restoration by fill placed along the entire eroded sector. Fill may be placed above MSL, below MSL, or at both.

a. Stockpiling. Stockpiling would probably be effective on Ludlam Beach because of the predominance of north-to-south longshore transport (Fig. 63). September would be the best month for stockpiling material at the north end of a problem area. From then until May, material could be expected to move south. The time interval after placement, during which a net southward movement would occur, would decrease until May. Between June and August material would move in a net north direction.

Transport reversals are also a consideration in siting a stockpile at the north end of the island. A longshore transport nodal point may exist about 1,500 feet south of the northern tip of the island. As evidenced by wave approach angle on the beach and on the submarine bar (Fig. 1), north of the nodal point net south-to-north longshore transport probably predominates. The nodal point appears to occur farther south (2,000 feet south of the north end of the island) on the submarine bar. Tidal currents adjacent to Corson Inlet also appear to significantly influence sediment transport in this region.

b. Direct Placement. Direct placement of beach material might also be an effective measure in stabilizing the coast in the shoreline indentation north and south of the Sea Isle City groin system. The volume loss rate from the filled beaches above MSL would probably decrease from north to south through the filled region because the updrift fill areas would provide sand to nourish downdrift fill areas. This condition was observed by Everts, DeWall, and Czerniak (1974) at Atlantic City after two beach fills (1963 and 1970). The loss rate, which was 0.25 cubic yard per foot-day per lineal foot of beach at the north end of the fill area, decreased at a rate of 0.0002 cubic yard per foot-day per lineal foot of beach in a southerly direction through the fill area.

The region at the north end of the island (Fig. 40, profile line 1) is eroding so severely (-6.8 cubic yards per foot-year) that artificial fill placed there would probably be rapidly lost unless the nourishment was accompanied by some form of fixed structure. The material in this inlet region is lost during storms (Fig. 32). Although the inlet migration trend from 1842 to 1955 was to the north, it was reversed from 1949 to 1974, moving an average 92 feet per year south (Fig. 56).

c. Time of Fill Placement. The behavior and effectiveness of artificial fill is time-dependent. Movement alongshore from north to south is predominant from September to May. This parallel-to-shore transport, as previously discussed, is especially important when using the stockpile method of fill placement. Onshore-offshore sediment movement should also be considered in planning beach nourishment projects. A significant seasonal loss of sand may be anticipated between October and May (Fig. 33). From May to October the sand returns to the beaches from offshore sources. This seasonal onshore-offshore movement at Ludlam Beach averages 18 cubic yards per foot.

To prevent interference with natural onshore nourishment, beaches should be nourished above MSL after most of the natural seasonal accretion has occurred (September or October). It is also important, however, that fill be placed before the onset of fall and winter storms if the objective of fill is to form a protective beach. Fill placed in early summer above the elevation of natural summer accretion will not inhibit natural nourishment. Nourishment by dumping in shallow water (< 10 feet) should be done in April or May to allow for the maximum movement of the fill sand to the beaches by natural processes. The amount this fill will interfere with the normal onshore sand movement is unknown.

If stockpiling is used to nourish the beach, the best month for placement is September for moving the material from north to south. For onshore movement and retention on the beach, fill should be placed in the spring in a location where it will not significantly interfere with the natural onshore movement of sediment. These criteria are not compatible. Thus, the selection of the time for placement must be a compromise of the different factors that distribute the material and of the design requirement, i.e., fill for recreational beach purposes, for coastal protection, or for both.

d. Loss Rates. An estimate of the short- and long-term volume fluctuations in the fill material is important in designing a safe width for a protective beach. It is difficult to predict the loss rates when using artificial fill. Generally, the loss rates in fill material have been found to exceed those of natural beach material at the same location even where the fill and native beach sand sites are similar. For example, Everts, DeWall, and Czerniak (1974) found loss rates for fill material placed in 1963 and 1970 at Atlantic City were much larger than loss rates of adjacent natural material. When averaged over the fill area, the loss rates were 12 and 9 times the mean annual loss from the entire subaerial beach.

The volume loss rate as a function of shoreline retreat is required when designing the width of a protective beach. Changes in sand volume above MSL are closely related to changes in the MSL shoreline position. Figure 68 shows sand volume change versus shoreline change between consecutive surveys. The resulting correlation coefficient is given in Figure 69. Figure 70 illustrates the ratio of volume change to shoreline change, averaged for each profile line at Ludlam Beach. A shoreline change of 1 foot is accompanied by an average sand volume change of about 3.6 cubic feet per foot. The range of values varies from 2.75 to 4.75 cubic feet per foot. The values are primarily a function of berm elevation and foreshore slope. The higher the berm elevation and the greater the average foreshore slope, the greater the volume loss or gain per unit retreat or advance of the shoreline.

2. Inlet Behavior.

Inlets bounding Ludlam Beach are characterized by an erratic shoreline, submarine bars, and shoal movements which typify inlets along sandy coasts. Their capacity to trap sand moving alongshore in the littoral system or moving onshore from seaward sources varies widely. Their capacity to provide sediment to the adjacent littoral zones and offshore region also varies just as widely. The pathline of sediment moving past Corson and Townsend Inlets also varies with some sediment bypassing around the inlets on the seaward ebb tidal shoals; other sediment moves into the inlet throat on the updrift side, then out again onto the downdrift island shore.

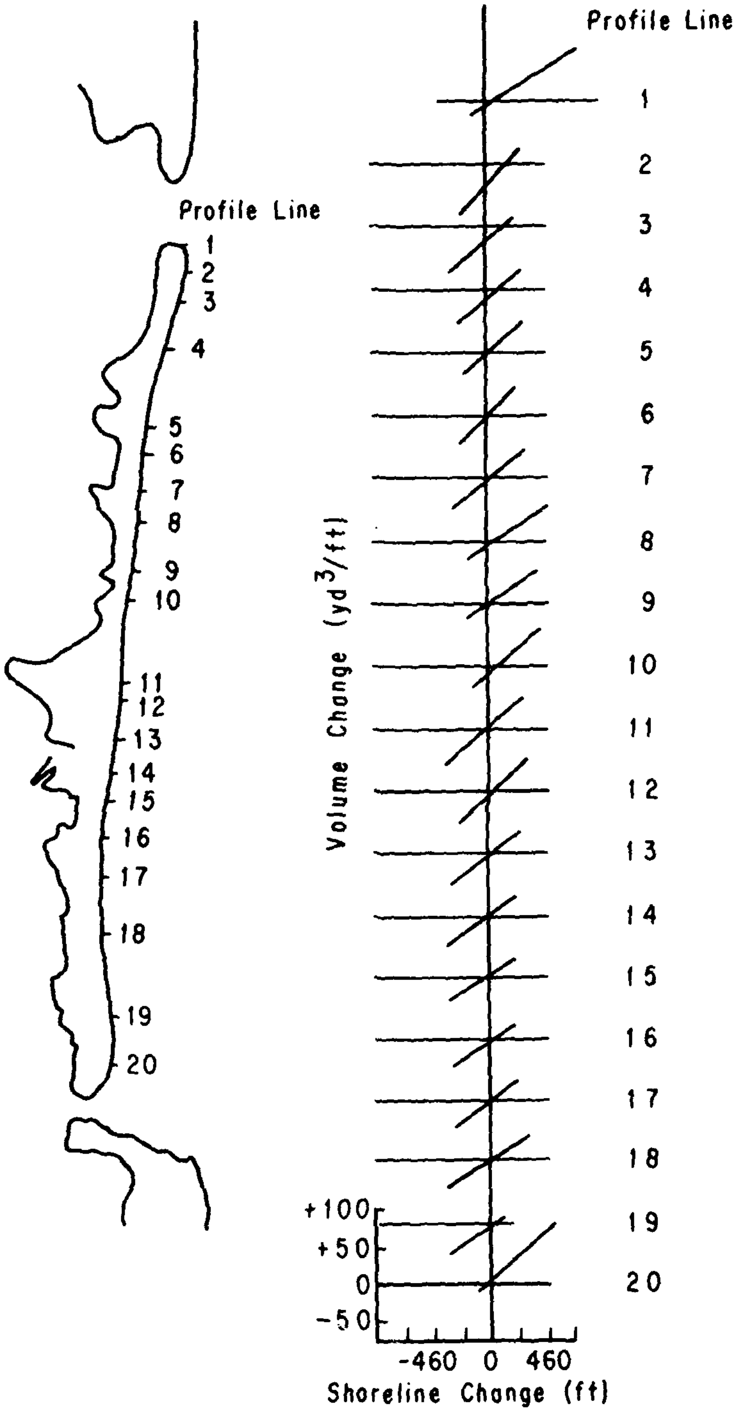

Figure 68. Sand volume change as a function of shoreline position change, illustrating a relatively consistent ratio along Ludlam Beach.

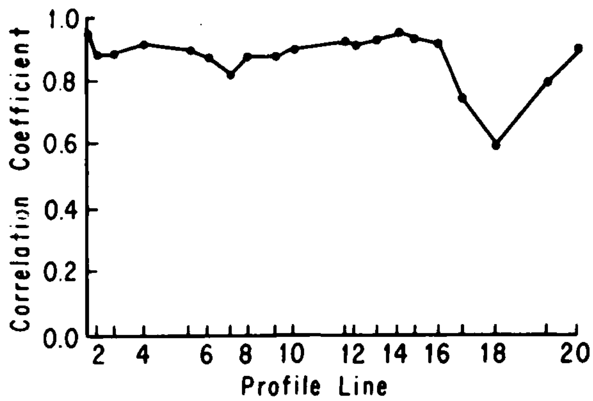

Figure 69. Correlation coefficients calculated for the regression curves shown in Figure 68 (shoreline change versus volume change).

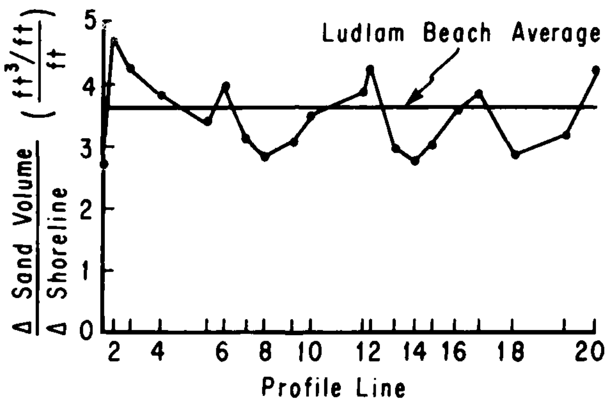

Figure 70. Mean sand volume changes above MSL which accompany shoreline retreat or advance along Ludlam Beach.

a. Corson Inlet. Historically, the migration of Corson Inlet has varied in direction and rate. From 1842 to 1955, the south shore of the inlet migrated 2,300 feet north, an average rate of 20 feet per year (Fig. 27); however, this trend was not constant. Between 1842 and 1899, for example, the position of the southern shore of the inlet remained nearly fixed. From 1949 to 1974 Corson Inlet migrated south at a rate of 92 feet per year (Fig. 56), about 4.5 times greater than the long-term northern migration trend, and the inlet width increased 1,900 feet (Fig. 55) or 76 feet per year. Width changes during the 1949-74 interval were highly variable while the migration rate was nearly constant. The change in position and width of the inlet was mostly due to erosion of the southern shore of the inlet. The northern shore of the inlet accreted and prograded south at 16 feet per year.

Channel thalweg position in Corson Inlet fluctuated between 1949 and 1974 with a general trend of moving from the south to the north side of the inlet. Thus, as the inlet widened and migrated south, the thalweg lagged behind the migration rate and changed its relative position to the north side of the throat.

Shifts in channel orientation at Corson Inlet were apparently gradual (Fig. 59). The inlet changed direction from north to south between 1949 and 1960, then progressively began to shift to a more southerly direction. The channel length (Fig. 60) is directly related to orientation. The channel is shortest when oriented toward its northern extreme. When oriented toward the south the channel length seaward of the throat may be 25 percent greater than when oriented 50° farther north. The period of change in orientation and channel length appears to be less than the period of inlet migration or per haps out of phase with the cycle of inlet migration to the south and with inlet widening.

b. Townsend Inlet. Historically, Townsend Inlet has migrated south at a rate of 9 feet per year (periods 1842-1955 and 1949-74). For the past 25 years the south shore of Townsend Inlet has been stabilized by groins and a bulkhead. The southerly migration has thus been at the expense of inlet width which has decreased at a near constant rate of 16 feet per year. The channel has remained near or slightly south of the center of the inlet during the southerly migration. There was no significant change in channel orientation from 1949 to 1974.

c. Beaches Adjacent to Inlets. Inlet shoaling may result in erosion of downdrift beaches; i.e., the inlet may be removing sand from the longshore transport system. The removal or release from the inlets may be gradual or abrupt. Although knowledge of the trapping and release mechanisms of inlets is limited, it is known that inlets act as a type of filter for material moving parallel to shore. Their removal and release period has a significant effect on the stability of downdrift beach and groin systems.

The changes in the plan area of visible bars (Fig. 61) and the change in shoreline position near the inlets are the only evidence available concerning volume changes in the inlet systems. Trends are not obvious in Figure 61. Note, however, that the plan area of the shallow ebb tidal bars can vary by as much as a factor of 8. The data in this report indicate no relationship between inlet migration, inlet widening, or channel behavior, and the volume of sand stored in ebb tidal shoals.

Inlet movements frequently cause a loss of sediment from one side of the inlet and a gain on the other side. Based on a simple regression analysis of Figure 62, the shore north of Corson Inlet gained land area at the rate of 0.006 square mile per year ($R = 0.90$, where R = correlation coefficient) during the 1949-74 period. The shore south of the inlet, i.e., the Strathmere shore, lost land area at a rate of 0.007 square mile per year ($R = -0.81$). The combined north and south shore changes, also shown in Figure 62, varied widely with a 25-year average loss of -0.00086 square mile per year ($R = -0.15$). Assuming a mean sand volume of 0.13 cubic yards above MSL per square foot of beach (Fig. 70), the average yearly sand volume gain to beaches north of Corson Inlet was 22,300 cubic yards and the average yearly loss was 26,000 cubic yards. The average yearly loss of sand from the inlet beaches was therefore 3,700 cubic yards.

Land area was gained from 1949 to 1974 on the north shore of Townsend Inlet at a rate of 0.001 square mile per year and lost from the south shore at the same rate, averaging ±400 cubic yards per year.

Storms appeared to be responsible for the changes which occurred at the north and south ends of Ludlam Beach (Fig. 32). At the south shore of Corson Inlet the average storm loss for seven storms was 20.4 cubic yards per foot per storm, or eight times as great as the average island loss. Conversely, at the south end of the beach storm losses were negligible (<0.3 cubic yard per foot per storm) and lower than any other location on the island. Beaches on the north side of Corson Inlet throat, because of their orientation, were shadowed by Peck Beach. Longshore transport during a "northeaster" is from north to south so the north beaches, when eroded, receive no sand from updrift sources. The southern beaches, on the other hand, are at the distal and shadowed end of the longshore transport system associated with the storm.

Not all storms follow the sequence of northern cut and southern fill. A result of the March 1962 storm was 0.05 square mile of new land created at the north end of Ludlam Beach (Fig. 62). At an average elevation of 3.6 feet (Fig. 70), this was an accretion of 186,000 cubic yards. During the same storm period land was created north of Corson Inlet at the same average rate (0.006 square mile per year) which existed over the 25-year (1949-74) study period. The new land formed south of the inlet was quickly lost. By spring 1963, the south shore was nearly back to its 25-year trend, and by 1965 the south shore losses were greater than the trend. One implication of these findings is that the sand wave shown on Figures 40 and 41, which began moving south in 1962, was composed of the storm-produced material. A further implication is that the sand wave resulted from a unique event which produced a large volume of sand at the north end of the island. Its initiation, therefore, cannot be predicted.

Seasonal sand volume changes were very large near Corson Inlet (Fig. 36, profile lines 1 to 4). The yearly minimum occurred in May, like the island average (Figs. 33 and 35), but the volume maximum above MSL generally occurred earlier in the summer (July to September). Losses correspond to storm periods, while gains are related to nonstorm periods. As shown in Figure 67, when the seasonal range of sand volume is greater than 12 cubic yards per foot, a net loss of 0.2 cubic yard per foot in excess of a seasonal 12 cubic yards per foot may be expected. Seasonal changes must be decreased to limit the net losses from the north end of the island.

The farthest distance away from an inlet at which beach behavior is affected by an inlet may be inferred from the survey data. Beaches near the inlets are oriented differently from those along the rest of the island (Fig. 21), a result of the inlet beaches being situated on coastal protrusions. Sand volume changes caused by storms (Fig. 32), seasonal sand volume changes (Fig. 35), and net yearly sand volume changes (Fig. 39) were significantly different on profile lines 1, 2, 19, and 20 when compared to other locations on Ludlam Beach. Corson Inlet appeared to have an effect on adjacent beaches for a distance 2,000 feet south along the northern shore of the island. This corresponded to the part of the coast affected by longshore transport reversals (Fig. 51). Submarine bars also appeared to intersect the coast at the southern end of the inlet-affected beaches. At Townsend Inlet the beach appeared affected 4,000 feet north of the southern shore of the island.

3. Effects of the Sea Isle City Groins.

Groins at Sea Isle City affect the coast north (updrift) and south (downdrift), as well as within the groin system. This occurs because the groins modify longshore and onshore-offshore movements of sand.

a. Beach Behavior. Groins at Sea Isle City are sited within and adjacent to a bulge in the coastline (Fig. 21). The bulge, which is not centered symmetrically over the groin system, appears to be positioned slightly north of the central groin. Beaches north and south of the bulge were erosional between 1962 and 1972 (Fig. 39). The southern one-third of the bulge was erosional while its northern two-thirds was stable or accretional.

Survey data on beach conditions before groin construction are not available. However, more than 100 years of shoreline position data from charts (Fig. 27) indicate the coastal reach where the groins exist today has fluctuated in position with an intermittent bulge. Historically, the region north of the groins was erosional (Fig. 39), although probably not as highly erosional as it was from 1962 to 1972. South of the groin region the coast was only slightly erosional before groin construction. From 1962 to 1972 downdrift beaches experienced intense erosion, perhaps the result of the groin system.

Between 1962 and 1972 the bulge had an alongcoast length of 9,000 feet (Fig. 39). Its accretional part was asymmetrical with an accretion maximum at the northernmost groin. From there a slight net yearly accretion occurred 4,500 feet to the north. Significant accretion was measured 4,500 feet to the south within the groin system. Ninety percent by volume of the accretion above MSL occurred within the groin system. In the southern 40 percent of the groin system the beach was highly erosional. In total, there was a 10,000-foot erosional reach south of the accretional bulge (Fig. 39). The erosional indentation was asymmetrical with the highest net yearly loss measured at the south end of the groins.

Within the groin system the total yearly accretion in the northern 3,700 feet was twice the total yearly loss in the southern 2,100 feet. In the 9,000-foot-long accretional bulge the net yearly gain of sand above MSL was 10,500 cubic yards while 13,500 cubic yards was lost in the 10,000-foot-long erosional indentation to the south. The net loss to the beach in the northern bulge and southern indentation was, therefore, 3,000 cubic yards per year or -0.16 cubic yard per foot-year. This loss is 14 percent of the average sand loss for the entire island. The actual section of beach affected by the groins is unknown. It seems reasonable, though, that the bulge and indentation were, at least in part, the result of changes in coastal processes and sediment availability at and adjacent to the groin system.

Seasonal changes in sediment volume above MSL in the coastal bulge were not in phase with those in the indentation or on the rest of the island (Fig. 35). From 6,000 feet north of the groins (profile line 8) to profile line 13 in the groin system, the yearly volume minimum occurred later in the year than the island average in May (see Fig. 33). The volume maximum also occurred later in the year (October). Seasonal volume changes in the indentation south of the bulge were similar to the island average.

The sand volume change from the yearly maximum to the yearly minimum was least within the groin system (Fig. 36), averaging 12 versus 18 cubic yards per year for the entire island. As shown previously (Fig. 67), a direct relationship exists between net yearly loss and the seasonal range of volume change, i.e., as range increases, loss increases. When the ratio of net yearly change to seasonal range, C, is plotted, as in Figure 71, a number of interesting conditions appear. The minimum C value on Ludlam Beach, C = -0.15, occurred in the three locations where the most critical erosion existed; i.e., at Corson Inlet and in the coastal indentations north and south of the groins. Additionally, the C values progressively increased to positive values from north to south in the region north of the Sea Isle City groins at a rate of +0.000044 per foot, and north of Townsend Inlet at +0.00002 per foot.

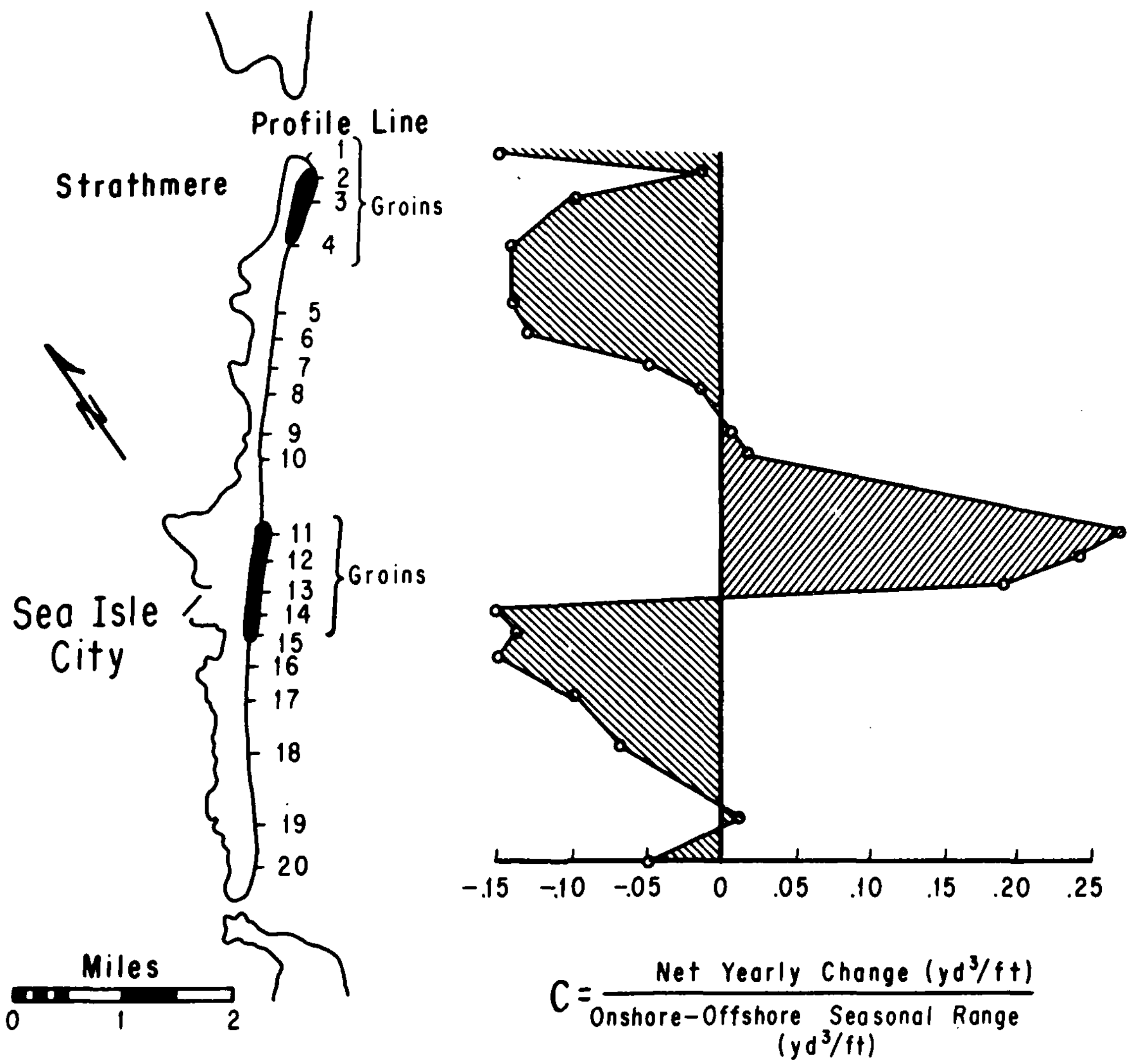

Figure 71. Relationship between net yearly sand volume change and seasonal range of sand volume above MSL. The ratio, C, is a dimensionless number. Note the minimum value of -0.15 in the coastal indentations.

Storm changes within the groin system were lower than the island average (Fig. 32). In general, storm losses in the indentations north and south of Sea Isle City were two to three times greater than those in the groins, suggesting the groins were effective in reducing storm loss. In the southern 40 percent of the groin system, however, the net yearly losses were large, probably because much of the sand lost from the beach was not replaced by sand from either offshore or updrift.

b. Coastal Processes. The response of the beach to various coastal processes is fairly well documented for the region above MSL. The actual mechanics of initial sediment movement, sediment transport, and deposition which causes the changes, however, are poorly understood. Longshore and onshore-offshore sediment transport data obtained in this study provide some information to assist in inferring where, when, and how much sediment moves.

Sediment movement is predominantly from north to south along Ludlam Beach. However, the sediment moving in the longshore transport system appeared to be deflected seaward by the groins, and returned to the subaerial beach considerably downcoast, causing a deficiency in available sediment supply south of Sea Isle City. In the northern section of the groins and updrift of the groins an accretional fillet formed which slightly changed the configuration of the coast.

The slight accretion north of the groins was partially caused by sediment moving south from the eroding indentation toward Strathmere. However, most of it was probably associated with the large volume of sediment moving south in the longshore transport system of the southern coast of New Jersey (about 400,000 cubic yards per year at Sea Isle City, Fig. 63). The material was trapped updrift of the groins which caused the configuration of the coast to prograde seaward in a very subtle fillet shape.

Groins at Sea Isle City may have their greatest effect on the downdrift coast by deflecting seaward the sand which is moving in an essentially parallel-to-shore direction. With the predominant wave-induced and south-directed longshore current on Ludlam Beach, the sediment is carried some distance downdrift before it is returned to the beach. Also, because it is carried to deeper water at a greater distance from shore, it will require a longer period to be transported to the subaerial beach than will the sediment moved offshore elsewhere along the island.

It appears that the centroid of sediment deflected seaward by the groins (Fig. 39) returned 7,000 feet south of profile line 13. The groins, thus, produced a downdrift "shadow zone" where less than the normal amount of sediment moved offshore was returned. As the net longshore component of sediment transport decreases, the shadow zone is expected to become shorter. The amount of sediment deflected seaward could probably be minimized if the seaward ends of the groins were submerged (Vallianos, U.S. Army Engineer District, Wilmington, N.C., personal communication, 1974). This would decrease the channeling effect and still trap sand moving parallel to shore. Currents channeled seaward apparently disrupted the submarine bar system off the groins. They also appeared to deflect it seaward (Figs. 47 and 48).

Seasonal accretion and erosion near the groins varied from the island average as a direct result of seasonal changes in the direction and magnitude of longshore transport (Fig. 63). This created the phase difference in cut and fill above MSL near the groins (Fig. 35). In the northern part of the groin system and north of the groins the beaches accreted most rapidly from August to December, the period of greatest net transport south. This is also the period when sediment was not available to the southern part of the groin system and the downdrift beaches. From January to May the northern beaches lost sand less rapidly than other areas of Ludlam Beach because longshore transport was also to the south. Although net shore-normal transport was offshore, the material moving south compensated for the offshore losses. From May through August, longshore transport was to the north. As shown in Figure 35, this resulted in net loss in the region immediately updrift of the groin field and gains in the south. May through August is a period of net onshore movement for the island (Fig. 33).

Storm losses above MSL were reduced within the groins when compared to the rest of Ludlam Beach (Fig. 32). This probably occurred because the updrift groin acted as a barrier to waves approaching shore at an acute angle while the downdrift groin trapped sand above MSL. Seaward of the MSL shoreline, however, significant erosion could occur, especially in the area where water is deflected seaward.

4. Sea Level Rise.

Sea level rise, which may or may not continue in the future, is rapid enough to influence the effectiveness of a shore structure during its project life. The retreat of the shoreline caused by a rise in sea level is an apparent one because no actual sand volume is lost. However, since structure effectiveness and the magnitude of shore processes are water-depth dependent, the rise is very important. For most practical purposes it should be considered in coastal engineering.

It is possible to determine the apparent loss of sediment from the active profile as caused by sea level rise. According to Hicks (1972) the rise of the water surface with respect to the adjacent land at Atlantic City is 0.015 foot per year (1920-70 period). A similar rate probably holds for Ludlam Beach. Assume the shore-normal profile shape remains in equilibrium with wave- and current-carried sediment out to some specified depth; i.e., the profile shape will not vary, but will be translated landward 0.5 foot per year for a foreshore slope of 0.03 and upward 0.015 foot per year, as shown in Figure 72. When the effective seaward limit of the active profile remains at a constant depth, the apparent sediment loss is approximately equal to one-half the depth of the seaward limit times the change in shoreline position.

An important difficulty in calculating the apparent sediment loss is in determining the "effective" seaward limit of sand movement to and from the beach. It has been suggested the limit exists at the boundary between the shore-parallel bathymetric contours and the seaward contours that do not follow the trend of the shore (U.S. Army, Corps of Engineers, Coastal Engineering Research Center, 1977). Although the Ludlam Beach region is irregular due to linear shoals directed northeasterly, it appears that shore parallelism terminates at or landward of the 40-foot contour.

An additional, but complementary, method of finding the limit is to obtain cross sections of the coast and check them for significant changes in shape

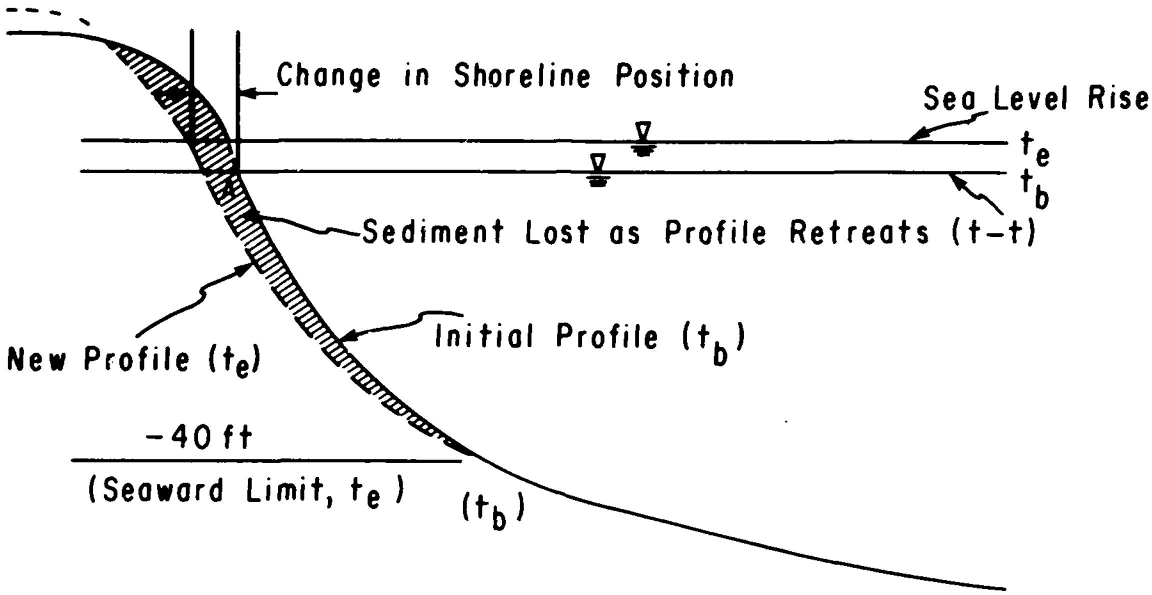

Figure 72. Schematic of apparent sediment loss volume as the shoreline retreats or sea level rises. t_b is beginning time and t_e is end time.

(slope) (Everts, 1978). Two profiles, which were composites of nine shore-normal profiles each, were taken 10 miles north of the study area (Atlantic City) and 10 miles south (Wildwood). Each of the profiles represents the average profile at the location, and visible changes in slope appear at 35- to 45-foot depths, an average of 40 feet. If -40 feet is assumed to be the effective seaward limit of sediment transport, the apparent sediment loss above MSL caused by a sea level rise at Ludlam Beach would be 0.75 cubic yard per foot-year or 23,000 cubic yards per year for the entire island coast.

5. Beach Surveys.

An important question in a beach study is when (time of year and frequency) and where (profile line spacing) to survey a beach to produce useful results. A survey program, of course, depends on how the survey data will be used. For the type of results discussed in this report, the following guidelines are given to assist in planning other beach survey programs.

a. Seasonal Considerations. A winter or spring survey will generally indicate less sand on the beaches than in the summer or fall (Fig. 33). The range of change between seasons is usually 2 to 20 times as great as the net yearly change. The average for Ludlam Beach was 16 times as great. Thus, the time of year the surveys are made is very important because seasonal changes can easily mask longer term changes. The survey program at Ludlam Beach indicates that 3 years of monthly surveys is required to determine the average seasonal change in sand volume on a beach. It must be noted that changes for a given year do not always follow the average seasonal trend, nor are they the same the length of the coast (Fig. 36). At Ludlam Beach the monthly change in beach volume deviated significantly from the island average in the Sea Isle City groins and at the south end of the island.

b. Yearly Considerations. Yearly changes in sand volume must also be considered when planning a survey program. On Ludlam Beach the net long-term change was -1.12 cubic yards per foot, but changes between years, both accretion and erosion, averaged twice that, and in some cases were four times greater (Fig. 37).

When planning a program for determining the net change in beach volume, a number of yearly records are needed. It should be noted that the migration of a sand wave past a specific beach site takes 10 to 11 years. Net volume change data obtained from surveys of less than a 10-year period would be biased by the sand wave.

c. Survey Frequency. As stated, a minimum of 10 years of survey data is needed to obtain a net yearly volume change rate. To obtain consistent data, surveys should be made on the same profile lines at the same time each year. Two surveys per year would probably be sufficient. The best times to survey are during intervals when the beach is not changing rapidly (Fig. 33): February to May (the seasonal volume minimum), when losses have stopped but material generally has not moved inshore above MSL, and July and August (the seasonal volume maximum), when winter storms have not, in general, removed too much sand from the beaches. Between these times the beaches above MSL are either rapidly gaining or losing sand.

d. Sand Waves. The possibility of migrating accretional features, up to 10 or 11 years past the time they began, should be considered when using beach surveys to determine changes in beach volume or shoreline position. Sand waves appear to occur after an event causes a large volume of beach sediment to accumulate on the updrift end of a barrier island. If such an event is suspected the presence of sand waves should be anticipated. The sand volume change caused by a migrating sand wave averaged 15 to 20 cubic yards per foot between the wave crest and trough on Ludlam Beach.

e. Profile Line Spacing. To determine the net yearly volume change on Ludlam Beach, away from the inlet and groin systems, a spacing of 2,000 to 3,000 feet was enough to pick up the alongshore trend in erosion or accretion. At the inlets a closer spacing of perhaps 1,000 feet is warranted. Within groin systems a profile line in the center of each groin compartment appears to be the least that will provide representative net long-term beach change data. The same spacings appear to be sufficient to determine seasonal changes (Fig. 33).

Trends of beach volume changes, when averaged for seven storms (Fig. 32), were not consistent in the indentations north and south of the Sea Isle City groins. This was especially true north of the groins. The spacing required to pick up these trends is unknown.

f. Volume Versus Shoreline Changes. In general, the beach volume above MSL is directly related to the position of the shoreline. In some instances, however, a progradation of the MSL shoreline occurs when the upper foreshore erodes. This condition has been observed, for example, after storms on Long Island (Everts, 1973) and at other east coast localities (DeWall, Pritchett, and Galvin, 1977; Birkemeier, 1979). Caution in interpreting beach volume change from shoreline position change on aerial photos is therefore suggested.

g. Offshore Surveys. Offshore surveys were not routinely made during the course of this study. However, the offshore should be surveyed, if possible, to account for the total sand budget. This is especially true in describing onshore-offshore movements of beach sand.

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VII. SUMMARY

This study investigated changes during a 10-year period (1962-72) in beach shape, shoreline position, and sand volume above MSL at 20 profile locations on Ludlam Beach, New Jersey. The plan shape of the 7.5-mile-long, 0.25- to 1.0-mile-wide barrier island is one in which the inlet shorelines protrude considerably seaward of the indentation near the island ends. Superimposed on that indentation is a shoreline bulge in the vicinity of the Sea Isle City groin system.

Beach width on the island averaged 260 feet with a range between 90 and 350 feet. Foreshore slopes averaged 0.03. Berms were present on 80 percent of the profile lines in August and 13 percent in January.

Surveys provided data on beach change above MSL, based on the location along the coast and on the time surveyed. Variations in shoreline position were large and associated with location. The average change in shoreline position was -8.2 feet per year. Sand volume losses from above MSL, resulting from seven storms, averaged 2.6 cubic yards per foot per storm or 90,000 cubic yards per storm. Overwash deposition, which occurred along 60 percent of the coast during the severe storm of March 1962, averaged 14.7 cubic yards per foot. However, such overwash events are rare. No significant overwash deposition occurred during this study. Losses on a specific profile line as the result of a storm are not predictable.

Clear seasonal trends in the volume of sand above MSL were evident. A net accretion occurred from June through October; November through May was a period of sand loss from the subaerial beach. The average difference in sand volume above MSL between the time of minimum sand volume (May) and maximum sand volume (October) was 18 cubic yards per foot. The least difference (< 10 cubic yards per foot) was measured in the Sea Isle City groin system.

Yearly changes in sand volume on Ludlam Beach varied from a gain of 2.9 cubic yards per foot (1964-65) to a loss of 4.6 cubic yards per foot (1966-67). Net yearly sand volume changes over the 10-year survey interval averaged -1.12 cubic yards per foot per year (a loss of 40,000 cubic yards per year from the entire island above MSL).

Sand volumes on Ludlam Beach increased and decreased in a time-ordered sequence from north to south during the 10-year study, indicating material moved alongshore and above MSL as a sand wave. The sand wave, which moved at a rate of 5 feet per day, had a wavelength of 16,000 feet and a volume of about 240,000 cubic yards. The sand wave apparently began after the March 1962 storm deposited about 200,000 cubic yards of material at the north end of the island.

Sediment transport on and off the beach each year (about 600,000 cubic yards) was somewhat greater than the magnitude of the net longshore transport rate to the south (430,000 cubic yards per year). Longshore transport was to the south from September through May, and to the north in June and July. The gross longshore transport rate was 1,150,000 cubic yards per year. A longshore transport reversal node appears to exist about 1,500 feet south of Corson Inlet. The amount of sand moved on and off the beach each month, above MSL, is directly related to the wave power expended on the beach. The relationship between yearly wave power and yearly sand volume losses or gains above MSL is less definitive.

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WATTS, G.M., "Behavior of Beach Fill and Borrow Area at Harrison County, Mississippi," TM-107, U.S. Army, Corps of Engineers, Beach Erosion Board, Washington, D.C., Aug. 1958.

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APPENDIX A

DEFINITIONS OF PROFILE GEOMETRY

1. Beach profile — The cross section of a beach surface (the intersection of a vertical plane and the beach).

2. Profile line — The line followed by surveyors in making a beach profile. The line is determined by two previously established fixed points (one of which is a bench mark or monument), or by one fixed point and an angle measured from a known direction.

3. Profile coordinates — The distance-elevation pairs of numbers measured by surveyors to locate a point on the beach profile.

4. Distance — The horizontal coordinate of a point on a beach profile, measured positively seaward from a fixed point on the profile line.

5. Elevation — Vertical coordinate of a point on a beach profile, measured positively upward from a known datum. The datum in this report is the National Geodetic Vertical Datum (NGVD) of 1929. In the field, elevation of a point on a beach profile is determined by measuring the vertical difference between the point and the monument whose elevation has been established.

6. Contour — A line of constant elevation along the beach surface (the intersection of a horizontal plane and the beach surface).

7. Contour intercept — The point defined by the intersection of a contour with a beach profile. On some profiles, there may be more than one intercept of a given contour.

8. Profile area — The area bounded above by a beach profile, landward by a vertical line, and below by a horizontal line. The vertical line intersects either the monument or the landward end of the beach profile. The horizontal line passes through the MSL contour intercept. Area was computed by a computer program which summed vertical trapezoidal areas whose upper corners were profile coordinates. At the seawardmost area, where the profile meets the MSL bound, the area is a triangle.

$$A(p,t) = \int_{x_1}^{x_2} y \, dx$$

9. Unit volume (beach storage) — The product of a cross-sectional area and a unit length perpendicular to the area, given in units of volume per length of shoreline, cubic yards per foot in this paper.

$$V(p,t) = A(p,t) \; \Delta s$$

10.	Unit volume change (storage change)	The difference between unit volumes measured by two surveys. If the landward end of one or both profiles does not reach the vertical line defined as the landward bound of the profile area, the landward bound is redefined to be a vertical line through the seawardmost of the landward ends of the two profiles. $\Delta V(p,t,t_o) = V(p,t) - V(p,t_o)$
11.	Storage change rate	Unit volume change divided by time between surveys.
12.	Beach width	The horizontal distance on a beach profile from the shoreline to the base of the frontal dune or bulkhead. Where the survey did not cross either dune or bulkhead, that profile was deleted.
13.	Shoreline	The MSL contour (in this paper). This contour was extrapolated, as necessary, from the seawardmost line segment which crossed at least the +2-foot contour.
14.	Mean monthly unit volume (profile line)	The average unit volume on the beach in a given month, obtained by adding the unit volumes from all surveys of the given profile line in the given month (regardless of year) and dividing by the number of surveys. $\overline{V}(p,t_m) = \frac{1}{N} \Sigma_i V(p,t_{mi})$
15.	Change in mean monthly unit volume (profile line)	The difference between (14) calculated for the given month and (14) calculated for the previous month. $\Delta\overline{V}(p,t_m,t_{m-1}) = V(p,t_m) - V(p,t_m - 1)$
16.	Mean monthly unit volume (locality)	The average of mean monthly unit volumes at a profile line (definition 14) for all profile lines at the locality, weighted by the distance between profile lines.
17.	Change in mean monthly unit volume (locality)	Difference between mean monthly unit volumes (definition 16) calculated for 2 successive months.
18.	Mean monthly shoreline position (profile line)	The average shoreline position in a given month, obtained by adding the shoreline positions from all surveys of the given profile in the given month (regardless of year) and dividing by the number of surveys. $\overline{MSL}(p,t_m) = \frac{1}{N} \Sigma_i MSL(p,t_{mi})$
19.	Change in mean monthly shoreline position (profile line)	The difference between (18) calculated for the given month and (18) calculated for the previous month. $\Delta\overline{MSL}(p,t_m,t_{m-1}) = MSL(p,t_m) - MSL(p,t_{m-1})$

20.	Mean monthly shoreline position (locality)	The average of mean monthly shoreline position at a profile (definition 18) for all profiles at the locality, weighted by distance between profile lines.
21.	Change in mean monthly shoreline position (locality)	Difference between mean monthly shoreline positions (definition 20) calculated for 2 successive months.
22.	Mean annual unit volume (profile line)	The average unit volume at a profile line for a given year, obtained by adding the unit volumes from surveys during the given year and dividing by the number of surveys. $$\overline{V}(p,t_y) = \frac{1}{N}\,\Sigma_i\, V(p,t_{yi})$$
23.	Change in mean annual unit volume (profile line)	The difference between (22) calculated for the given year and (22) calculated for the previous year. $$\Delta\overline{V}(p,t_y,t_{y-1}) = \overline{V}(p,t_y) - \overline{V}(p,t_{y-1})$$
24.	Mean annual unit volume (locality)	The average of mean annual unit volumes at a profile line (definition 22) for all profile lines at the locality, weighted by the distance between profile lines.
25.	Change in mean annual unit volume (locality)	The difference between mean annual unit volumes (definition 24) calculated for 2 successive years.
26.	Mean annual shoreline position (profile line)	The average shoreline position at a profile line for a given year, obtained by adding the shoreline positions from surveys during the given year and dividing by the number of surveys. $$\overline{MSL}(p,t_y) = \frac{1}{N}\,\Sigma_i\, MSL(p,t_{yi})$$
27.	Change in mean annual shoreline position (profile line)	The difference between (26) calculated for the given year and (26) calculated for the previous year. $$\Delta\overline{MSL}(p,t_y,t_{y-1}) = \overline{MSL}(p,t_y) - \overline{MSL}(p,t_{y-1})$$
28.	Mean annual shoreline position (locality)	The average of mean annual shoreline positions at a profile line (definition 26) for all profile lines, weighted by the distance between profile lines.
29.	Change in mean annual shoreline position (locality)	The difference between mean annual shoreline positions (definition 28) calculated for 2 successive years.

APPENDIX B

PROFILE LINE LOCATIONS, LUDLAM BEACH

This appendix contains descriptions of the monument location for the 20 profile lines at Ludlam Beach. Absolute third-order horizontal and vertical control is tied to the New Jersey grid. Monuments are also referenced to local features to expedite recovery.

COUNTRY	TYPE OF MARK	STATION	
U. S. A.	disk set, in conc. mon.	Profile line 1 BE-A-2 Sta. -4+00	
LOCALITY Ludlam Island Strathmere, NJ	STAMPING ON MARK BE-A-2 -4+00	AGENCY (CAST IN MARKS) Corps of Engrs.	ELEVATION 8.87 (FT) (M)
LATITUDE 39°12'08.57"	LONGITUDE 74°39'12.88"	DATUM	DATUM Sea Level Datum 1929
(NORTHING)(EASTING) (FT) 134 410 (M)	(EASTING)(NORTHING) (FT) 2003 709 (M)	GRID AND ZONE NJ Trans. Merc.	ESTABLISHED BY (AGENCY) Corps of Engineers
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE Jan 1975 / ORDER

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC) ° ' "	BACK AZIMUTH ° ' "	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)

The station is located at the north end of Ludlam Island in Strathmere, New Jersey, north-northwest of the centerline intersection of Commonwealth Avenue, and Seaview Road. The monument is flush with the ground.

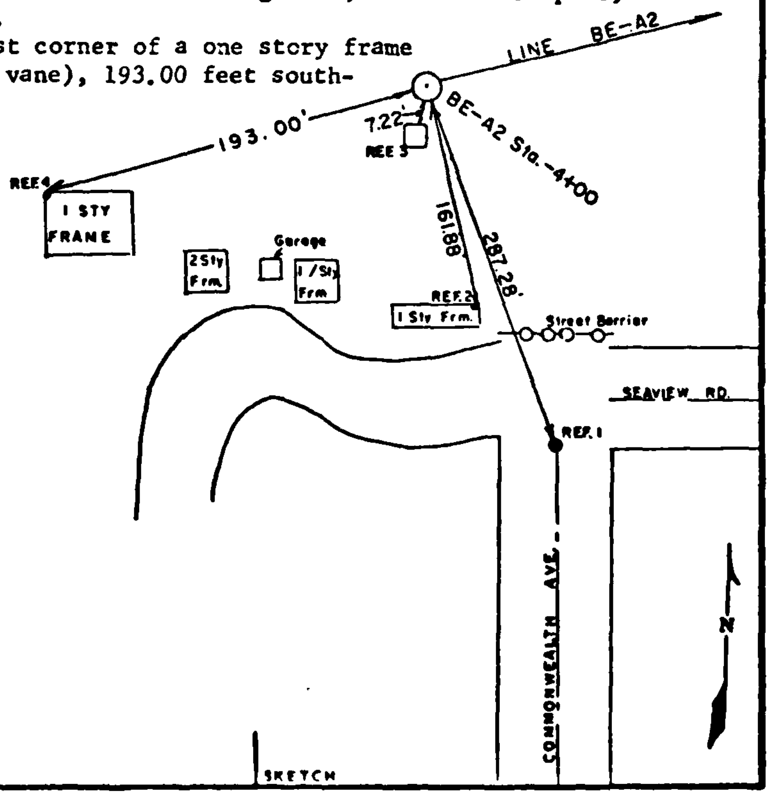
Reference 1 is a PK nail at the centerline intersection of Commonwealth Avenue and Seaview Road, 287.28 feet south-southeast of the station.

Reference 2 is the northeast corner of a one story frame house at the north end of Commonwealth Avenue, 161.88 feet south of the station.

Reference 3 is a PK nail, 2.5 feet above the ground, in a 3" x 3" post, 7.22 feet south of the station.

Reference 4 is the northwest corner of a one story frame house (with cupola and weather vane), 193.00 feet southwest of the station.

NJ Grid Azimuth of Line BE-A
241°51'



COUNTRY U. S. A.	TYPE OF MARK COE disk set, in conc.mon.	STATION Profile line 2 BE-B-Sta. 2+20	
LOCALITY Ludlam Is. Strathmore, NJ	STAMPING ON MARK BE-B 2+20	AGENCY (CAST IN MARKS) Corps of Engrs.	ELEVATION 7.45 (FT)
LATITUDE 39°12'04.93"	LONGITUDE 74°39'08.90"	DATUM	DATUM Sea Level Datum 192
(NORTHING)(EASTING) (FT) 134 042	(EASTING)(NORTHING) (FT) 2 004 023	GRID AND ZONE NJ Trans. Merc.	ESTABLISHED BY (AGENCY) Corps of Engineers
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE Dec 1974 / ORDER

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ' "	° ' "		

The station is located at the north end of Ludlam Island in Strathmere, New Jersey at the east end of Seaview Road, on the north side of the street, just east of the drive way leading to house No. 23 Seaview Road (Daltons residence at present time). The monument is flush with the ground.

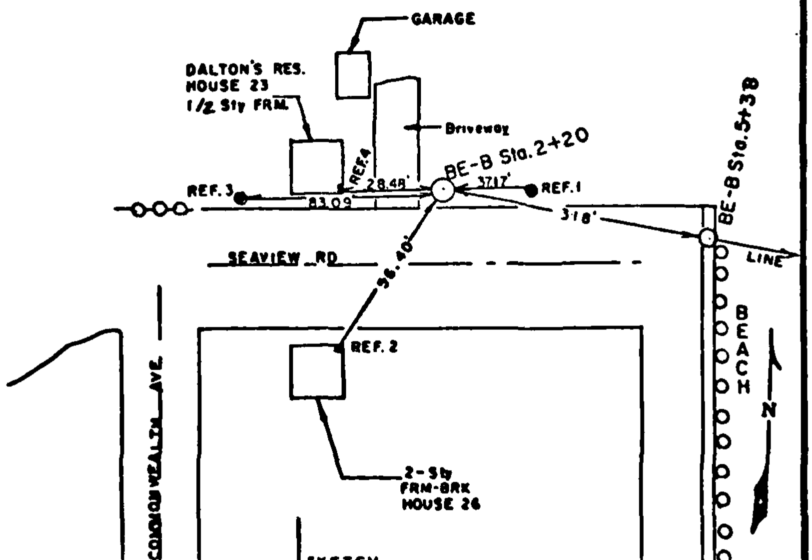
Reference 1 is a PK nail, 1.0 feet above the ground, in A.C.E. pole #3962, 37.17 feet east of the station.

Reference 2 is the northeast corner of a two story frame and brick house on the south side of Seaview Road, 56.40 feet south-southwest of the station.

Reference 3 is a PK nail, 1.0 feet above the ground, in A.C.E. pole #3579, 83.09 feet west of the station.

Reference 4 is the southeast corner of residence No. 23 Seaview Road, 28.48 feet west of the station.

NJ Grid Azimuth of Line BE-B 304°50'



SKETCH

DA FORM 1959 1 OCT 64 REPLACES DA FORMS 1958 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
For use of this form, see TM 5-237; the proponent agency is U.S.Continental Army Command.

COUNTRY	TYPE OF MARK	STATION	
U. S. A.	COE, Disk	BE-C Sta. 3+90 Profile line 3	
LOCALITY Ludlam Island Strathmere, NJ	STAMPING ON MARK BE-C-3+90	AGENCY (CAST IN MARKS) Corps of Engineers	ELEVATION 7.65 (FT) (M)
LATITUDE 39°12'00.05"	LONGITUDE 74°39'22.39"	DATUM	DATUM Sea Level Datum 1929
(NORTHING)(EASTING) (FT) (M) 133548	(EASTING)(NORTHING) (FT) (M) 2 002 961	GRID AND ZONE NJ Trans. Merc.	ESTABLISHED BY (AGENCY) Corps of Engineers
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE Jan 1975 / ORDER

TO OBTAIN	GRID AZIMUTH, ADD ° ' "	TO THE GEODETIC AZIMUTH
TO OBTAIN	GRID AZ. (ADD)(SUB.) ° ' "	TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ' "	° ' "		

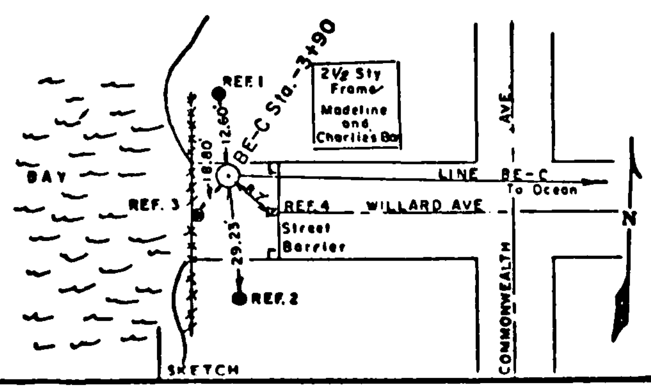
The station is located on Ludlam Island, in Strathmere, New Jersey at the west (bay side) end of Willard Avenue, just west of the north end of the street barrier and is flush with the roadway.

Reference 1 is a PK nail, 2.0 feet above the ground, in A.C.E. pole No 3603, 12.60 feet north of the station.

Reference 2 is a PK nail, 4.0 feet above the ground, in B.T. pole #22-287, 29.23 feet south of the station.

Reference 3 is a PK nail in centerline of roadway, 18.80 feet southwest of the station.

NJ Grid Azimuth of Line BE-C 311°-24'



DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION

For use of this form, see TM 5-237; the proponent agency is U.S.Continental Army Command.

COUNTRY	TYPE OF MARK	STATION	
U. S. A.	COE disk, set in conc.mon.	Profile line 4 BE-D Sta 2+00 10 So.	
LOCALITY Ludlam Island Strathmere, NJ	STAMPING ON MARK BE-D 2+00 10 So.	AGENCY (CAST IN MARKS) Corps of Engineers	ELEVATION 8.17 (FT) (M)
LATITUDE 39°11'38.82"	LONGITUDE 74°39'32.35"	DATUM	DATUM Sea Level Datum 1929
(NORTHING)(EASTING) (FT) 131 400 (M)	(EASTING)(NORTHING) (FT) 2 002 177 (M)	GRID AND ZONE NJ Trans Merc	ESTABLISHED BY (AGENCY) Corps of Engineers
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE Jan 1975 / ORDER

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ' "	° ' "		

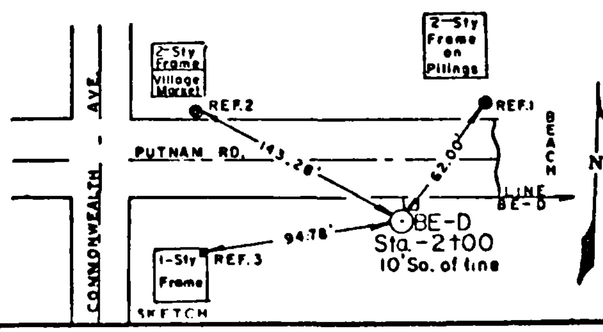
The station is located on Ludlam Island in Strathmere, New Jersey at the east end of Putnam Road, 10 feet south of the south curb, approximately 40 west of the inshore toe of the dune. It is 10 feet south and 90 degrees to the section line. The monument is 0.1 feet beneath the surface of the ground.

Reference 1 is a PK nail, 1.0 feet above the ground, in A.C.E. pole W-27239, 62.00 feet northeast of the station.

Reference 2 isa PK nail, 2.0 feet above the ground, in A.C.E. Pole W-27238, 143.28 northwest of the station.

Reference 3 is the northeast corner of a one story frame house at the southeast corner of Commonwealth Avenue and Putnam Road, 94.78 feet west of the station.

NJ Grid Azimuth of Line BE-D 308°45'



DA FORM 1 OCT 64 1959 REPLACES DA FORMS 1958 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
For use of this form, see TM 5-237; the proponent agency is U.S.Continental Army Command.

COUNTRY	TYPE OF MARK	STATION	
U. S. A.	COE disk set in conc.mon.	Profile line 5 BE-E Sta-0+35	
LOCALITY Ludlam Island Strathmere, NJ	STAMPING ON MARK BE-E -0+35	AGENCY (CAST IN MARKS) Corps of Engineers	ELEVATION 5.59 (FT)
LATITUDE 39°11'13.36"	LONGITUDE 74°39'58.79"	DATUM	DATUM Sea Level Datum 1929
(NORTHING) (FT) 128 824	(EASTING) (FT) 2 000 095	GRID AND ZONE NJ Trans. Merc.	ESTABLISHED BY (AGENCY) Corps of Engineers
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE Dec 1974 / ORDER

TO OBTAIN GRID AZIMUTH, ADD ° TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC) ° ' "	BACK AZIMUTH ° ' "	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)

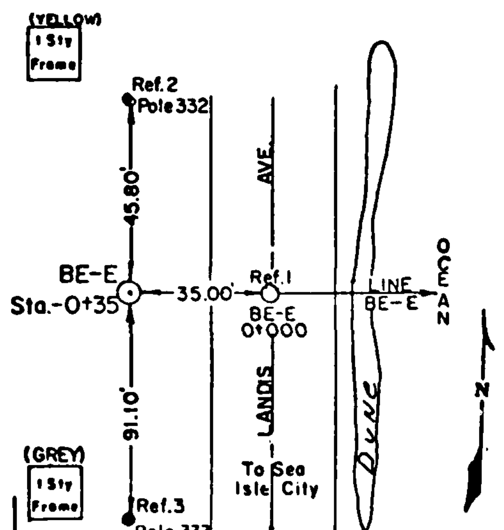
The station is located on Ludlam Island, 0.65 miles south on Landis Avenue from the intersection of Commonwealth Avenue (Landis Avenue extended) and Putnam Road in Strathmere, New Jersey. It is approximately 14 feet west of the west edge of the roadway and on line with the pole line. The monument is flush with the ground.

Reference 1 is a railroad spike in the centerline of Landis Avenue, 35.00 feet east of the station. (Station 0+00 on the section line)

Reference 2 is a PK nail, 1.0 feet above the ground, in Pole 332-09802, 45.80 feet north of the station.

Reference 3 is a PK nail, 1.0 feet above the ground, in Pole 333-W17021, 91.10 feet south of the station.

NJ Grid Azimuth of Line BE-E 304°47'



SKETCH

COUNTRY	TYPE OF MARK	STATION	
U. S. A.	COE disk set in conc. mon.	Profile line 6 BE-F Sta. -0+33	
LOCALITY Strathmere, NJ Ludlam Island	STAMPING ON MARK BE-F -0+33	AGENCY (CAST IN MARKS) Corps of Engineers	ELEVATION 7.27 (FT) (M)
LATITUDE 39°11'02.17"	LONGITUDE 74°40'08.80"	DATUM	DATUM Sea Level Datum 192
(NORTHING)(EASTING) (FT) 127 692	(EASTING)(NORTHING) (FT) 1 999 307	GRID AND ZONE NJ Trans. Merc.	ESTABLISHED BY (AGENCY) Corps of Engineers
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE Dec 1974 / ORDER

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ' "	° ' "		

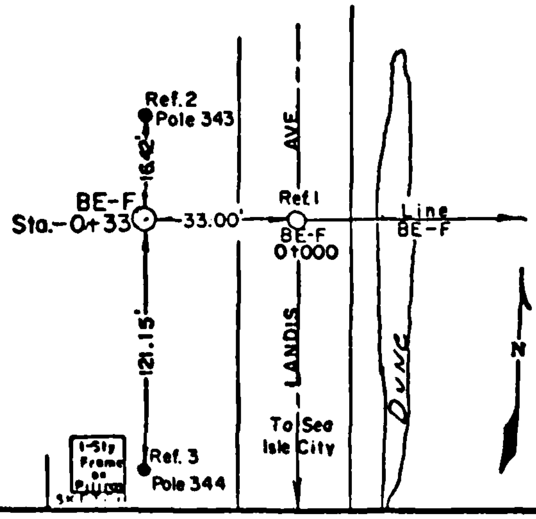
The station is located on Ludlam Island, 0.90 miles south on Landis Avenue from the intersection of Commonwealth Avenue (Landis Avenue extended) and Putnam Road in Strathmere, New Jersey. It is approximately 12 feet west of the west edge of the roadway and on line with the pole line. The monument is flush with the ground.

Reference 1 is a railroad spike in the centerline of Landis Avenue, 33.00 feet east of the station. (Station 0+00 on the section line)

Reference 2 is a PK nail, 3.0 feet above the ground, in Pole 343-W-27103, 16.42 feet north of the station.

Reference 3 is a PK nail, 2.0 feet above the ground, in Pole 344-W 28122, 121.15 feet south of the station.

NJ Grid Azimuth of Line BE-F 304°55'



DA FORM 1959 1 OCT 64 REPLACES DA FORMS 1958 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE. DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
For use of this form, see TM 5-237; the proponent agency is U.S.Continental Army Command.

COUNTRY	TYPE OF MARK	STATION	
U. S. A.	COE disk set in conc. mon.	Profile line 7 BE-G Sta-0+32	
LOCALITY Strathmere, NJ Ludlam Island	STAMPING ON MARK BE-G 0+32	AGENCY (CAST IN MARKS) Corps of Engineers	ELEVATION 6.65 (FT) ~~(M)~~
LATITUDE 39°10'49.00"	LONGITUDE 74°40'20.33"	DATUM	DATUM Sea Level Datum 1929
(NORTHING)~~(EASTING)~~ (FT) 126 360 ~~(M)~~	(EASTING)~~(NORTHING)~~ (FT) 1 998 399 ~~(M)~~	GRID AND ZONE NJ Trans. Merc.	ESTABLISHED BY (AGENCY) Corps of Engineers
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE Dec 1974 / ORDER

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ' "	° ' "		

The station is located on Ludlam Island, 1.25 miles south on Landis Avenué from the intersection of Commonwealth Avenue (Landis Avenue extended) and Putnam Road in Strathmere, New Jersey. It is approximately 15 feet west of the west edge of the roadway and opposite the "Dolphin Motel". The monument is 0.2 feet beneath the surface of the ground.

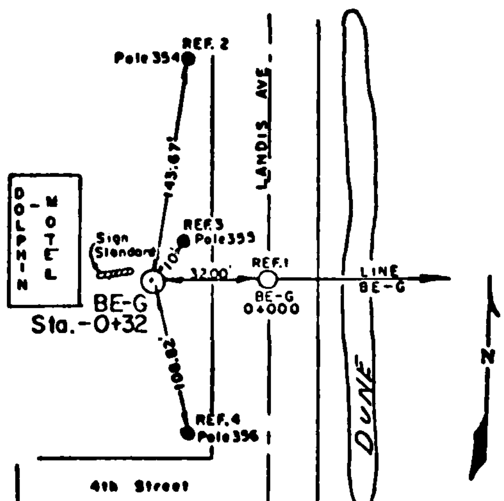
Reference 1 is a railroad spike in the centerline of Landis Avenue, 32.00 feet east of the station. (Station 0+00 on the section line)

Reference 2 is a PK nail, 2.0 feet above the ground in Pole #354, 143.67 feet north of the station.

Reference 3 is a PK nail, 2.0 feet above the ground, in Pole 22/355-W 27802, 10.00 feet northeast of the station.

Reference 4 is a PK nail, 2.0 feet above the ground, in Pole 356-W-27207, 108.82 feet south of the station.

NJ Grid Azimuth of Line BE-G 301°-33'



SKETCH

DA FORM 1 OCT 64 1959 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
For use of this form, see TM 5-237; the proponent agency is U.S. Continental Army Command.

COUNTRY	TYPE OF MARK	STATION	
U. S. A.	COE disk set in conc. mon.	Profile line 8 BE-H Sta. -0+33	
LOCALITY Sea Isle City Ludlem Island	STAMPING ON MARK BE-H -0+33	AGENCY (CAST IN MARKS) Corps of Engineers	ELEVATION 6.36 (FT) ~~(M)~~
LATITUDE 39°10'39.59"	LONGITUDE 74°40'28.07"	DATUM	DATUM Sea Level Datum 1929
(NORTHING)~~(EASTING)~~ (FT) 125 408 ~~(M)~~	(EASTING)~~(NORTHING)~~ (FT) 1 997 789 ~~(M)~~	GRID AND ZONE NJ Trans. Merc.	ESTABLISHED BY (AGENCY) Corps of Engineers
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE Dec 1974 / ORDER

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ' "	° ' "		

The station is located on Ludlam Island, 1.47 miles south on Landis Avenue from the intersection of Commonwealth Avenue (Landis Avenue extended) and Putnam Road in Strathmere, New Jersey. It is on the west side of the roadway, approximately 12 feet west of the pole line. The monument is flush with the ground.

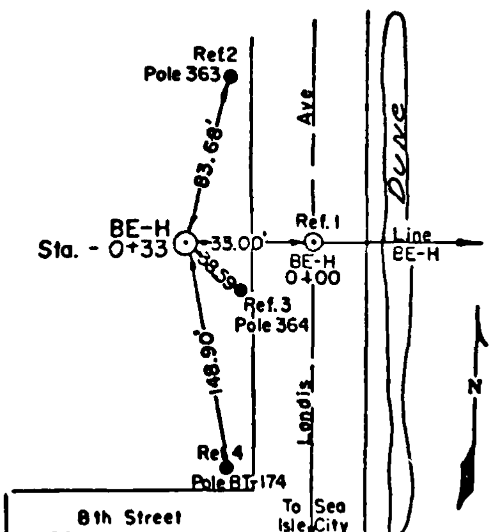
Reference 1 is a railroad spike in the centerline of Landis Avenue, 33.00 feet east of the station. (Station 0+00 on the section line)

Reference 2 is a PK nail, 1.0 feet above the ground, in pole 363, 83.68 feet north of the station.

Reference 3 is a PK nail, 1.0 feet above the ground, in pole 364, 38.59 feet south-southeast of the station.

Reference 4 is a PK nail in pole BT-174-51-W29490, 148.90 feet south the station.

NJ Grid Azimuth of Line BE-H 302°35'



SKETCH

DA FORM 1 OCT 64 1959 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE. DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION For use of this form, see TM 5-237; the proponent agency is U.S.Continental Army Command.

COUNTRY	TYPE OF MARK	STATION	
U. S. A.	COE disk set in conc. mon.	Profile line 9 BE-J Sta. ⁻0+35	
LOCALITY Ludlam Island Sea Isle City, NJ	STAMPING ON MARK BE-J ⁻0+35	AGENCY (CAST IN MARKS) Corps of Engineers	ELEVATION 7.50 (FT) ~~(M)~~
LATITUDE 39°10'22.94"	LONGITUDE 74°40'41.77"	DATUM	DATUM Sea Level Datum 1929
(NORTHING)~~(EASTING)~~ (FT) 123 724 ~~(M)~~	(EASTING)~~(NORTHING)~~ (FT) 1 996 711 ~~(M)~~	GRID AND ZONE NJ Trans. Merc.	ESTABLISHED BY (AGENCY) Corps of Engineers
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE Dec 1974 / ORDER

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ' "	° ' "		

Station is located on Ludlam Island, in Sea Isle City, New Jersey, 1.85 miles south on Landis Avenue from the intersection of Commonwealth Avenue (Landis Avenue extended) and Putnam Road in Strathmere. It is approximately 15 feet west of the west edge of the roadway, on line with the pole line and just north of residence No. 1412. The monument is flush with the ground.

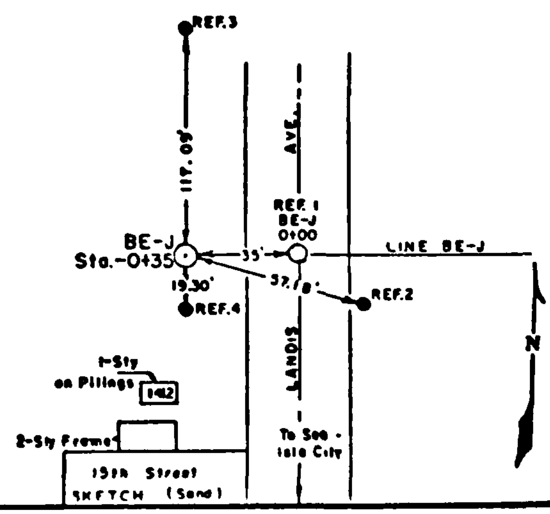
Reference 1 is a railroad spike in the centerline of Landis Avenue, 35.00 feet east of the station. (Station 0+00 on the section line)

Reference 2 is a PK nail, 1.0 feet above the ground, in north face of pole (no number) on east side of Landis Avenue, 57.18 feet east of the station.

Reference 3 is a PK nail, 1.0 feet above the ground, in pole 377, 117.09 feet north of the station.

Reference 4 is a PK nail, 3.0 feet above the ground, in pole 378, 19.30 feet south of the station.

NJ Grid Azimuth of Line BE-J 302°-34'



DA FORM 1 OCT 64 1959 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION

For use of this form, see TM 5-237; the proponent agency is U.S. Continental Army Command.

COUNTRY	TYPE OF MARK	STATION	
U. S. A.	COE disk set in conc. mon.	Profile line 10 BE-K Sta. -0+33	
LOCALITY Ludlam Island Sea Isle City, NJ	STAMPING ON MARK BE-K -0+33	AGENCY (CAST IN MARKS) Corps of Engineers	ELEVATION 6.47 (FT)
LATITUDE 39°10'12.43"	LONGITUDE 74°40'50.36"	DATUM	DATUM Sea Level Datum 1929
(NORTHING) (FT) 122 660	(EASTING) (FT) 1 996 034	GRID AND ZONE NJ Trans. Merc.	ESTABLISHED BY (AGENCY) Corps of Engineers
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE Jan 1975 / ORDER

TO OBTAIN GRID AZIMUTH, ADD ° TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ (ADD)(SUB.) ° TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ' "	° ' "		

The station is located on Ludlam Island, in Sea Isle City, New Jersey, 2.10 miles south on Landis Avenue from the intersection of Commonwealth Avenue (Landis Avenue extended) and Putnam Road in Strathmere. It is approximately 12 ft. west of the west edge of the roadway and 7.7 ft. west of a sign - 19th Street, (no street at present time). The monument is set flush with the ground.

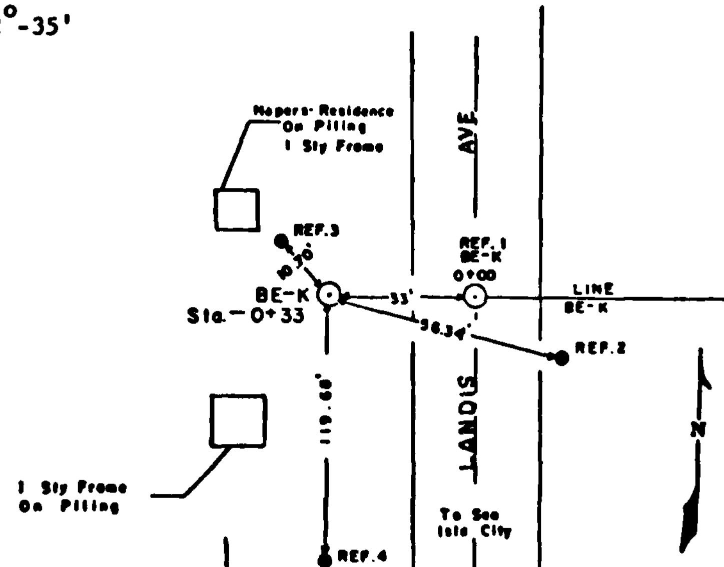
Reference 1 is a railroad spike in the centerline of Landis Avenue, 33.00 ft. east of the station. (Station 0+00 on the section line)

Reference 2 is a PK nail, 2.0 feet above the ground, in A.C.E. pole 3754, 56.34 ft. east of the station.

Reference 3 is a PK nail, 1.5 ft. above the ground, in pole 387-W22189, 10.70 feet north of the station.

Reference 4 is a PK nail, 3.0 feet above the ground, in pole 388-W26825, 119.68 feet south of the station.

NJ Grid Azimuth of Line BE-K 302°-35'



SKETCH

DA FORM 1959 1 OCT 64 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
For use of this form, see TM 5-237; the proponent agency is U.S.Continental Army Command.

COUNTRY	TYPE OF MARK	STATION	
U. S. A.	COL disk set in conc.mon.	Profile line 11 BE-L Sta. 3+10	
LOCALITY Ludlam Island Sea Isle City, NJ	STAMPING ON MARK BE-L 3+10	AGENCY (CAST IN MARKS) Corps of Engineers	ELEVATION 11.57 (FT)
LATITUDE 39°09'39.32"	LONGITUDE 74°41'09.14"	DATUM	DATUM Sea Level Datum 1929
(NORTHING) (FT) 119 311	(EASTING) (FT) 1 994 554	GRID AND ZONE NJ Trans. Merc.	ESTABLISHED BY (AGENCY) Corps of Engineers
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE Jan 1975 / ORDER

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ' "	° ' "		

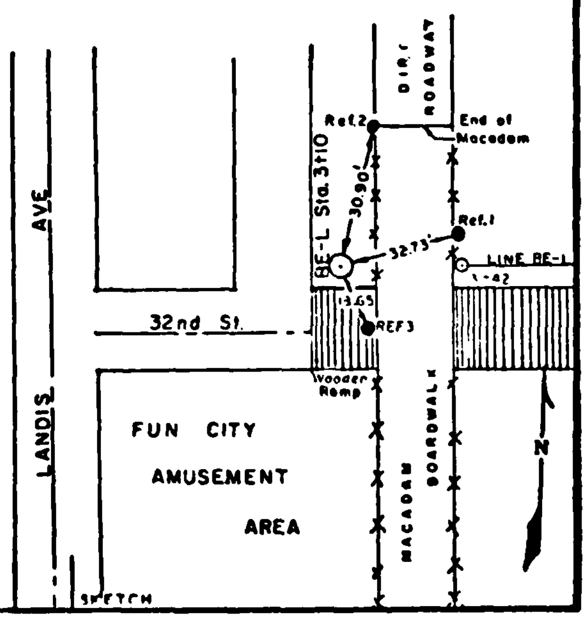
The station is located on Ludlam Island at Sea Isle City, New Jersey, at the east end of 32nd Street, 7 feet west of the west edge of the macadam boardwalk and 2 ft. north of the north side of the wooden ramp leading to the west side of the boardwalk. The monument is flush with the ground.

Reference 1 is the southwest corner of a metal light pole base #W32332, 32.73 ft. east of the station.

Reference 2 is a PK nail in the whaler on the west side and at the north end of the macadam boardwalk, 30.90 ft. north of the station.

Reference 3 is a PK nail at the top and in the center of the wooden ramp leading to the west side of the boardwalk, 18.65 ft. south of the station.

NJ Grid Azimuth of Line BE-L 291°-14'



DA FORM 1 OCT 64 1959 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
For use of this form, see TM 5-237; the proponent agency is U.S.Continental Army Command.

COUNTRY	TYPE OF MARK COE	STATION	
U. S. A.	disk	Profile line 12 BE-M Sta. 3+58	
LOCALITY Ludlam Island Sea Isle City, NJ	STAMPING ON MARK BE-M 3+58	AGENCY (CAST IN MARKS) Corps of Engineers	ELEVATION 12.24 (FT) XM
LATITUDE 39°09'34.24"	LONGITUDE 74°41'12.23"	DATUM	DATUM Sea Level Datum 1929
(NORTHING)(XXXXXX) (FT) 118 796 XXX	(EASTING)(XXXXXXX) (FT) 1 994 310 XXX	GRID AND ZONE NJ Trans. Merc.	ESTABLISHED BY (AGENCY) Corps of Engineers
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE Jan 1975 / ORDER

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ' "	° ' "		

The station is located on Ludlam Island at Sea Isle City, New Jersey at the east end of 34th Street on the centerline extended, 1.7 ft. east of the west edge of the macadam boardwalk. The disk is flush with the surface of the boardwalk.

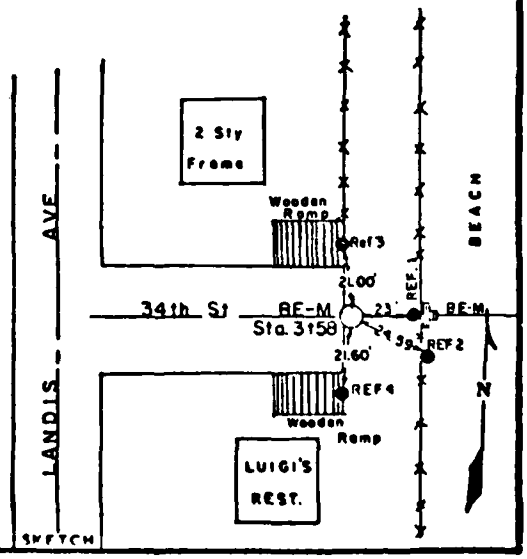
Reference 1 is a PK nail in the top step and center of the steps leading to the beach, 23.00 feet east of the station.

Reference 2 is the northwest corner of a base for metal light pole W-32336, on the east side of the boardwalk, 24.5 feet southeast of the station.

Reference 3 is a PK nail in the top center of a wooden ramp on the north side on 34th Street, 21.00 ft. north of the station.

Reference4 is a PK nail in the top center of a wooden ramp on the south side of 34th Street, 21.60 ft. south of the station.

NJ Grid Azimuth of Line BE-M 302°-44'



COUNTRY	TYPE OF MARK	STATION	
U. S. A.	COE disk	Profile line 13 BE-N Sta. 4+14	
LOCALITY Ludlam Island Sea Isle City, NJ	STAMPING ON MARK BE-N 4+14	AGENCY (CAST IN MARKS) Corps of Engineers	ELEVATION 12.36 (FT) (M)
LATITUDE 39°09'19.94"	LONGITUDE 74°41'23.13"	DATUM	DATUM Sea Level Datum 1929
(NORTHING)(EASTING) (FT) 117 350 (M)	(EASTING)(NORTHING) (FT) 1 993 452 (M)	GRID AND ZONE NJ Trans. Merc.	ESTABLISHED BY (AGENCY) Corps of Engineers
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE Jan 1975 / ORDER

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ' "	° ' "		

The station is located on Ludlam Island at Sea Isle City, New Jersey, at the east end of 40th Street extended, 1 ft. east of the west edge of the macadam at the front center of a seating area. The disk is flush with the boardwalk.

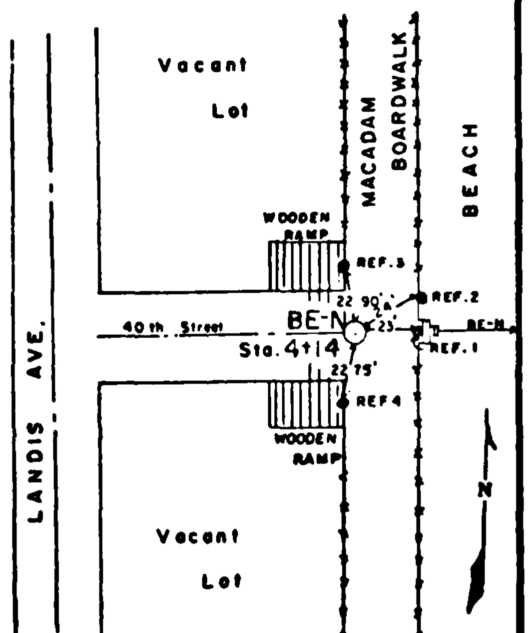
Reference 1 is a PK nail in the top step and center of the steps leading to the beach, 23.00 feet east of the station.

Reference 2 is the southwest corner of a base for metal light pole W-27894, 24.00' east of the station.

Reference 3 is a PK nail in the top center of a wooden ramp on the north side of 40th Street, 22.90 feet north of the station.

Reference 4 is a PK nail in the top center of a wooden ramp on the south side of 40th Street, 22.75 feet south of the station.

NJ Grid Azimuth of Line BE-N 302°-41'



SKETCH

DA FORM 1 OCT 64 1959 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
For use of this form, see TM 5-237; the proponent agency is U.S.Continental Army Command.

COUNTRY: U. S. A.	TYPE OF MARK: COE disk	STATION: Profile line 14 BE-P Sta. 3+93 24' No.	
LOCALITY: Ludlam Island Sea Isle City, NJ	STAMPING ON MARK: BE-P 3+93 24' No.	AGENCY (CAST IN MARKS): Corps of Engrs	ELEVATION: 7.69 (FT)
LATITUDE: 39°09' 07.71"	LONGITUDE: 74°41' 33.50"	DATUM:	DATUM: Sea Level Datum 1929
(NORTHING): 116 113 (FT)	(EASTING): 1 992 634 (FT)	GRID AND ZONE: NJ Trans. Merc.	ESTABLISHED BY (AGENCY): Corps of Engineers
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE:	DATE: Jan 1975 — ORDER:

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID)(MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ' "	° ' "		

The station is located on Ludlam Island at Sea Isle City, New Jersey, at the east end of 45th Street, at the north edge of the north sidewalk in front of a three story house (last house on the north side of the street) and approximately 0.5 feet south of the north edge of the north sidewalk. It is 24 feet north of and 90 degrees to the section line. The disk is flush with the sidewalk.

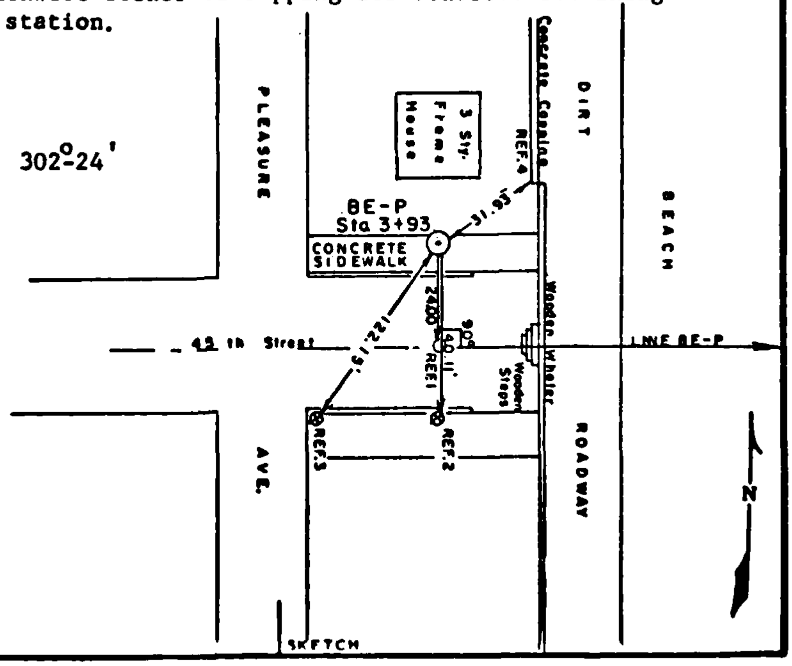
Reference 1 is a railroad spike in the centerline of 45th Street, 24.00 feet south of the station (station 3+93 on section line).

Reference 2 is a PK nail, 3.0 feet above the ground, in pole 4007, 40.11 feet south of the station.

Reference 3 is a PK nail, 1.0 feet above the ground, in pole 4006, 122.15 feet southwest of the station.

Reference 4 is the southwest corner of capping for concrete retaining wall, 31.93 feet east of the station.

NJ Grid Azimuth of Line BE-P 302°24'



DA FORM 1959, 1 OCT 64 — REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
For use of this form, see TM 5-237; the proponent agency is U.S.Continental Army Command.

COUNTRY	TYPE OF MARK	STATION	
U. S. A.	COE disk	Profile line 15 BE-Q Sta. 4+00 19.5' No.	
LOCALITY Ludlam Island Sea Isle City, NJ	STAMPING ON MARK BE-Q 4+00 19.5' No.	AGENCY (CAST IN MARKS) Corps of Engrs.	ELEVATION 8.69 (FT)
LATITUDE 39°08'58.30"	LONGITUDE 74°41'41.21"	DATUM	DATUM Sea Level Datum 1929
(NORTHING) (FT) 115 161	(EASTING) (FT) 1 992 027	GRID AND ZONE NJ Trans. Merc.	ESTABLISHED BY (AGENCY) Corps of Engineers
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE Jan 1975 / ORDER

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ' "	° ' "		

The station is located on Ludlam Island in Sea Isle City, New Jersey, at the end of 49th Street, in front of the last house on the north side of the street and set in the curb approximately 30 feet west of the wooden retaining wall. It is 19.45 feet north of and 90 degrees to the section line. The disk is flush with the curb line.

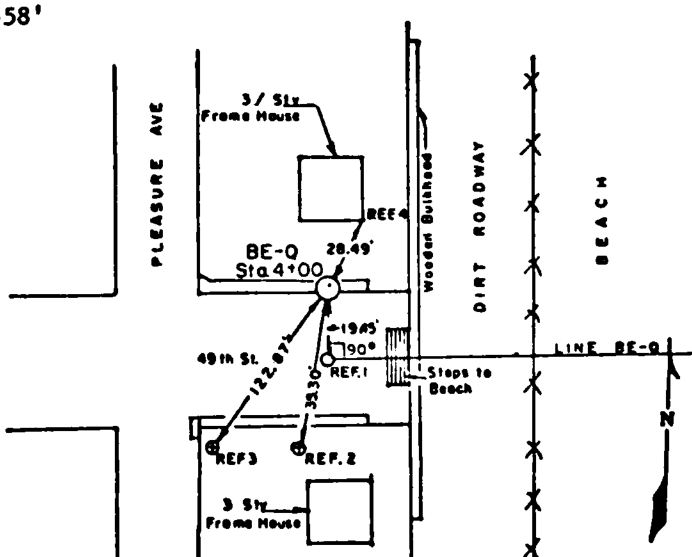
Reference 1 is a railroad spike in the centerline of 49th Street, 19.45 feet south of the station (station 4+00 on the section line).

Reference 2 is a PK nail, 1.5 feet above the ground, in pole 4047, 35.30 feet south of the station.

Reference 3 is a PK nail, 1.0 feet above the ground, in pole C-4046, 122.87 feet southwest of the station.

Reference 4 is the southeast corner of a 3½ story frame house (last house on the north side of the street), 28.49 feet northeast of the station.

NJ Grid Azimuth of Line BE-Q 302°-58'



SKETCH

DA FORM 1 OCT 64 1959 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
For use of this form, see TM 5-237; the proponent agency is U.S.Continental Army Command.

COUNTRY U. S. A.	TYPE OF MARK COE disk	STATION Profile line 16 BE-R Sta. 4+00 20' So.	
LOCALITY Ludlam Island Sea Isle City, NJ	STAMPING ON MARK BE-R 4+00 20' So.	AGENCY (CAST IN MARKS) Corps of Engineers	ELEVATION 7.78 (FT)
LATITUDE 39°08'43.94"	LONGITUDE 74°41'52.89"	DATUM	DATUM Sea Level Datum 1929
(NORTHING) (FT) 113 709	(EASTING) (FT) 1 991 106	GRID AND ZONE NJ Trans. Merc.	ESTABLISHED BY (AGENCY) Corps of Engineers
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE Jan 1975 / ORDER

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC) ° ' "	BACK AZIMUTH ° ' "	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)

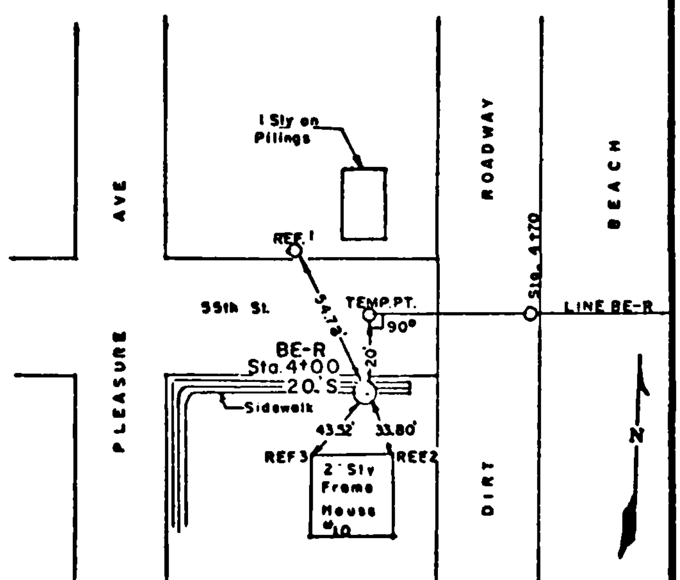
The station is located on Ludlam Island, In Sea Isle City, New Jersey, near the east end of 55th Street in front of a two story frame house (No. 10, last house on the street) on the south side of the street and set in the sidewalk. It is 20 ft. south of and 90 degrees to the section line. The disk is flush with the sidewalk.

Reference 1 is a PK nail, 1.0 feet above the ground, in pole BT916-5-09196, 54.78 ft. north of the station.

Reference 2 is the northeast corner of a two story frame house, 33.80 feet south of the station.

Reference 3 is the northwest corner of the two story frame house, 43.52 feet southwest of the station.

NJ Grid Azimuth of Line BE-R 302o-22'



SKETCH

DA FORM 1 OCT 64 1959 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
For use of this form, see TM 5-237; the proponent agency is U.S.Continental Army Command.

COUNTRY	TYPE OF MARK COE	STATION Profile line 17	
U. S. A.	disk	BE-S Sta. 4+28	
LOCALITY Ludlam Island Sea Isle City, NJ	STAMPING ON MARK BE-S 4+28	AGENCY (CAST IN MARKS) Corps of Engrs	ELEVATION 9.68 (FT)
LATITUDE 39°08'29.60"	LONGITUDE 74°42'02.86"	DATUM	DATUM Sea Level Datum 1929
(NORTHING) (FT) 112 259	(EASTING) (FT) 1 990 320	GRID AND ZONE NJ Trans. Merc.	ESTABLISHED BY (AGENCY) Corps of Engineers
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE Jan 1975 / ORDER

TO OBTAIN GRID AZIMUTH, ADD ° TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID)(MAGNETIC) ° ' "	BACK AZIMUTH ° ' "	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)

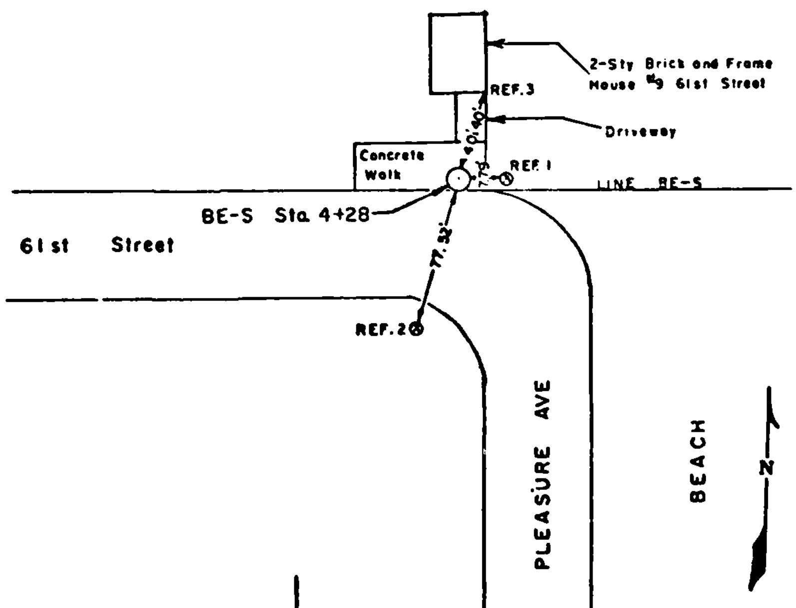
The station is located on Ludlam Island, in Sea Isle City, New Jersey, near the east end of 61st Street in front of a two story brick frame house (No. 9) on the north side of the road at the east end of the concrete walk.

Reference 1 is a PK nail, 0.5 feet above the ground, in pole ACE-W-20045, 7.79 feet east of the station.

Reference 2 is a PK nail, 0.5 feet above the ground, in pole ACE-20046, 77.52 feet south of the station.

Reference 3 is the southeast corner of the two story house, 40.40 feet north of the station.

NJ Grid Azimuth of Line BE-S 301°-11'



SKETCH

DA FORM 1 OCT 64 1959 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
For use of this form, see TM 5-237; the proponent agency is U.S. Continental Army Command.

COUNTRY	TYPE OF MARK COE	STATION Profile line 18	
U. S. A.	disk	BE-T Sta. 5+50	
LOCALITY Ludlam Island Sea Isle City, NJ	STAMPING ON MARK BE-T 5+50	AGENCY (CAST IN MARKS) Corps of Engrs.	ELEVATION 9.13 (FT) ~~(M)~~
LATITUDE 39°08'09.35"	LONGITUDE 74°42'15.52"	DATUM	DATUM Sea Level Datum 1929
(NORTHING)~~(EASTING)~~ (FT) 110 210 ~~(M)~~	(EASTING)~~(NORTHING)~~ (FT) 1 989 322 ~~(M)~~	GRID AND ZONE NJ Trans.Merc.	ESTABLISHED BY (AGENCY) Corps of Engineers
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE Jan 1975 / ORDER

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ' "	° ' "		

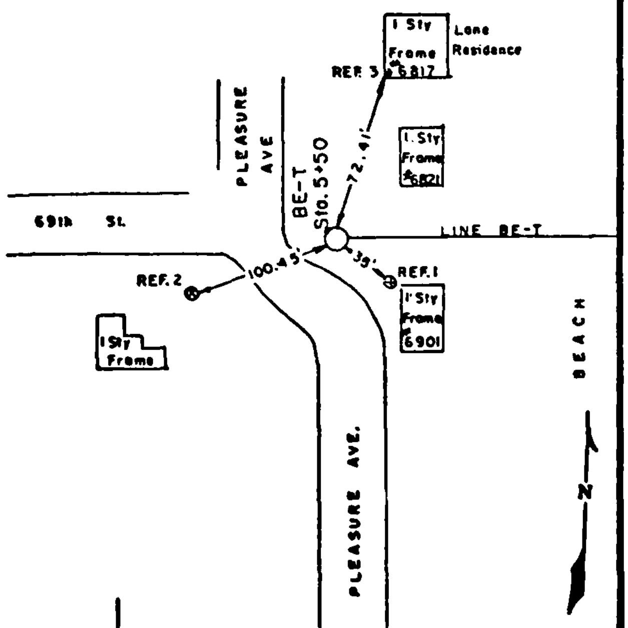
The station is located on Ludlam Island in Sea Isle City, New Jersey, at the east end of 69th Street on line with the south curb line. The monument is flush with the ground.

Reference 1 is a PK nail, 1.0 feet above the ground, in pole ACE-W-24423, 35.00 feet southeast of the station.

Reference 2 is a PK nail, 1.0 feet above the ground, in pole ACE-W-21995, 100.45 feet southwest of the station.

Reference 3 is the southwest corner of a one story frame house (No. 6817), 72.41 feet north northeast of the station.

NJ Grid Azimuth of Line BE-T 299°05'



SKETCH

DA FORM 1 OCT 64 1959 REPLACES DA FORMS 1958 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
For use of this form, see FM 5-237; the proponent agency is U.S.Continental Army Command.

COUNTRY U. S. A.	TYPE OF MARK COE disk	STATION Profile line 19 BE-U Sta. 0+00 20'No.	
LOCALITY Ludlam Island Townsend Inlet, NJ	STAMPING ON MARK BE-U 0+00 20'No.	AGENCY (CAST IN MARKS) Corps of Engineers	ELEVATION 10.26 (FT) ~~(M)~~
LATITUDE 39°07'33.46"	LONGITUDE 74°42'31.69"	DATUM	DATUM Sea Level Datum 1929
(NORTHING)(~~EASTING~~) (FT) 106 579 ~~(M)~~	(EASTING)(~~NORTHING~~) (FT) 1 988 046 ~~(M)~~	GRID AND ZONE NJ TransMerc.	ESTABLISHED BY (AGENCY) Corps of Engineers
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE Jan 1975 / ORDER

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ' "	° ' "		

The station is located on Ludlam Island in Townsends Inlet, New Jersey, at the east end of 84th Street in the center of a dirt driveway leading to the last house on the north side of the street and is 3.8 feet north of the north edge of the street. It is 20 feet north of and 90 degrees to the section line. The monument is flush with the ground.

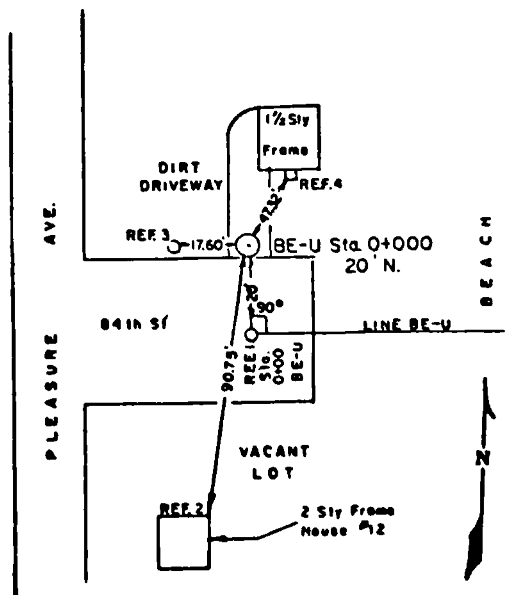
Reference 1 is a railroad spike in the centerline of 84th Street, 20 feet south of the station (station 0+00 on the section line).

Reference 2 is the northeast corner of a two story frame house on the south side of the street, 90.75 feet south-southwest of the station.

Reference 3 is a PK nail, 2.0 feet above the ground, in pole ACE-5564, 17.60 feet west of the station.

Reference 4 is the southwest corner of the brick chimney on a 1½ story frame house, the last house on the north side at the east end of 84th Street, 47.32 feet northeast of the station.

NJ Grid Azimuth of Line BE-U 291°-42'



SKETCH

DA FORM 1 OCT 64 1959 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
For use of this form, see TM 5-237; the proponent agency is U.S.Continental Army Command.

COUNTRY U. S. A.	TYPE OF MARK COE disk	STATION Profile line 20 BE-V Sta. 0+00 40' So.	
LOCALITY Ludlam Island Townsend Inlet, NJ	STAMPING ON MARK BE-V 0+00 40' So.	AGENCY (CAST IN MARKS) Corps of Engrs.	ELEVATION 10.18 (FT) ~~(M)~~
LATITUDE 39°07'17.65"	LONGITUDE 74°43'02.82"	DATUM	DATUM Sea Level Datum 1929
(NORTHING)~~(EASTING)~~ (FT) 104 981 ~~(M)~~	(EASTING)~~(NORTHING)~~ (FT) 1 985 592 ~~(M)~~	GRID AND ZONE NJ Trans. Merc.	ESTABLISHED BY (AGENCY) Corps of Engineers
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE Jan 1975 / ORDER

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ' "	° ' "		

The station is located on Ludlam Island in Townsends Inlet, New Jersey, near the east end of 93rd Street and on the centerline of Pleasure Avenue extended. It is 40 feet south of and 90 degrees to the section line. The monument is flush with the ground.

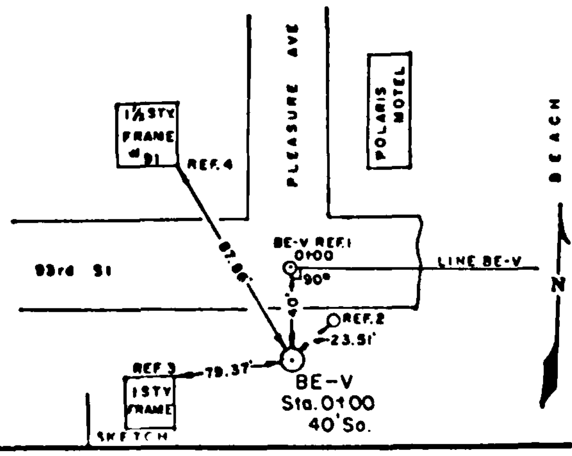
Reference 1 is a railroad spike in the centerline intersection of 93rd Street and Pleasure Avenue, 40 feet north of the station (station 0+00 on the section line).

Reference 2 is a PK nail, at ground level, in pole 15470, 23.51 feet northeast of the station.

Reference 3 is the northeast corner of a one story frame house on the south side of the street, 79.37 feet west of the station.

Reference 4 is the southeast corner of a one and a half story frame house (No.91) at the northwest corner of 93rd Street and Pleasure Avenue, 87.86 feet north-northwest of the station.

NJ Grid Azimuth of Line BE-V 294°-57'



SKETCH

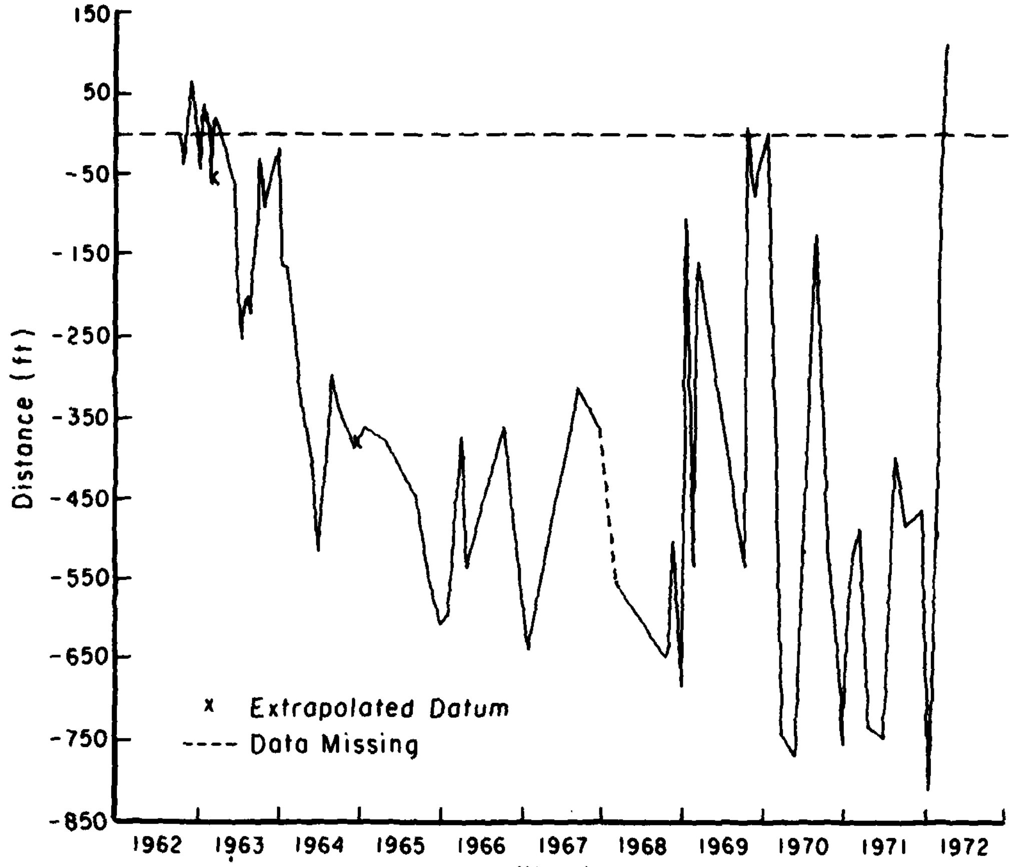
DA FORM 1959, 1 OCT 64 — REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
For use of this form, see TM 5-237; the proponent agency is U.S. Continental Army Command.

APPENDIX C

SHORELINE CHANGES, OCTOBER 1962 TO JULY 1972

This appendix presents changes in the position of the shoreline at the MSL elevation at Ludlam Beach, New Jersey. Position is referenced to zero for the first survey. Positive values indicate shoreline advance beyond the shoreline position. Negative values indicate retreat. Shoreline location is the horizontal position of the intersection of the profile and zero (MSL) elevation of the 1929 sea level datum. If there is more than one MSL intercept, the seawardmost is shown. An asterisk is given where the MSL intercept did not reach, but was extended to MSL elevation. Profile line locations are given in Appendix B.



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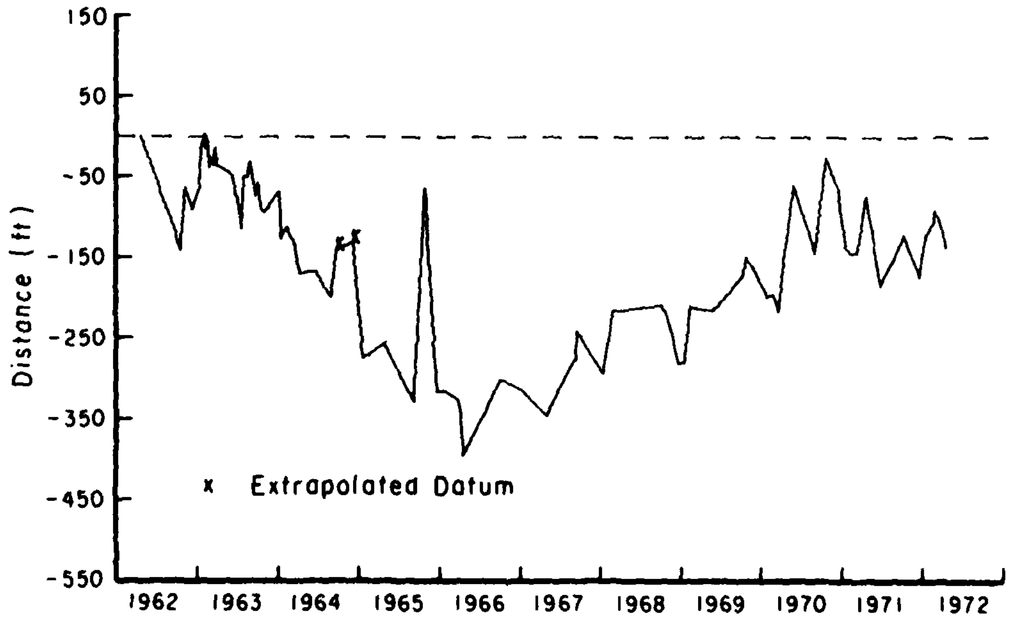

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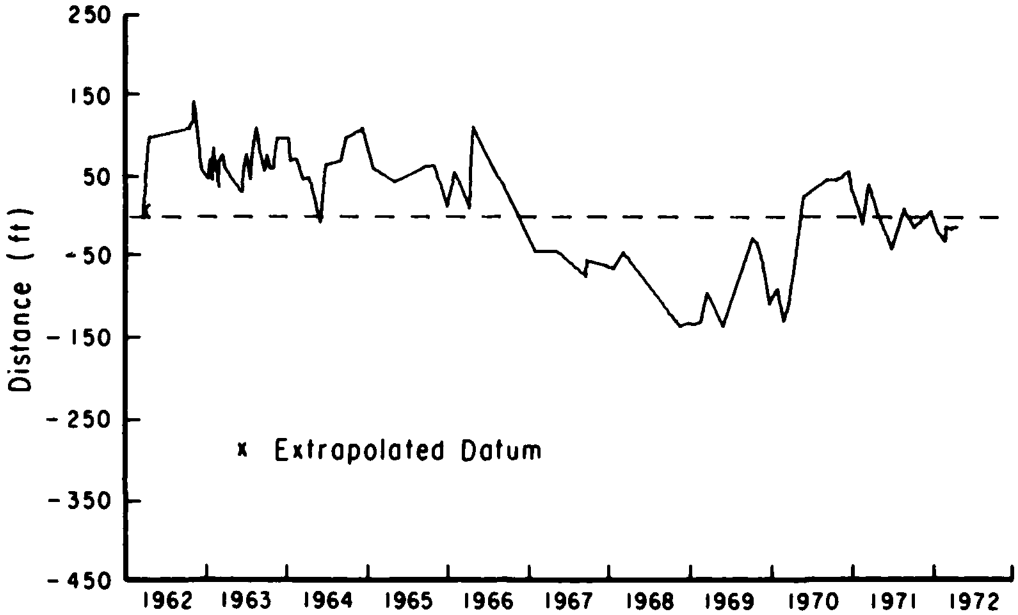

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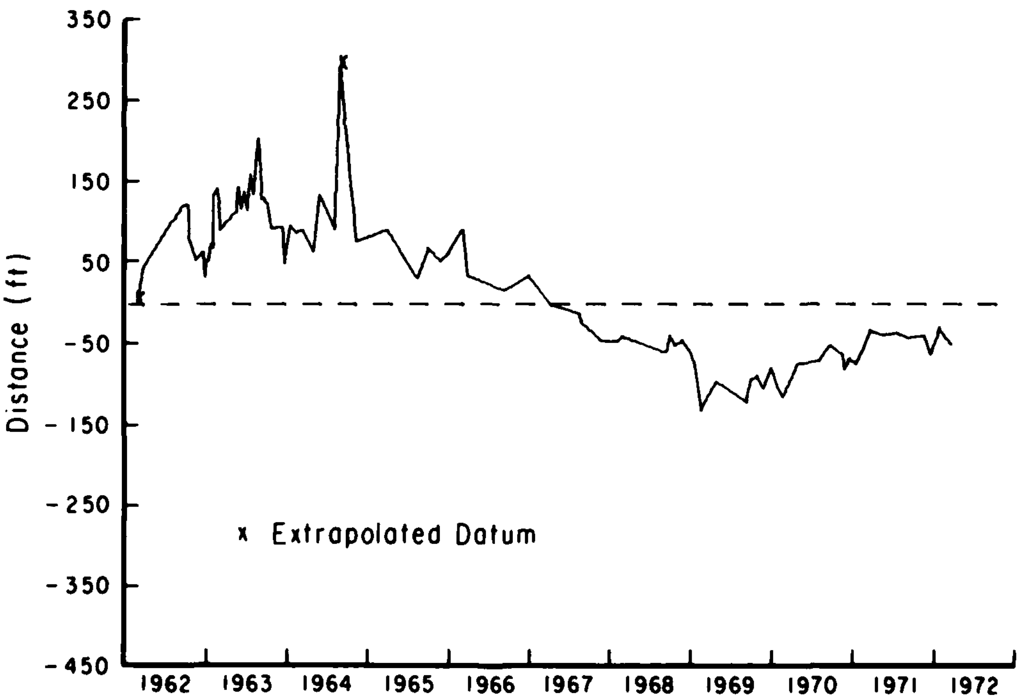

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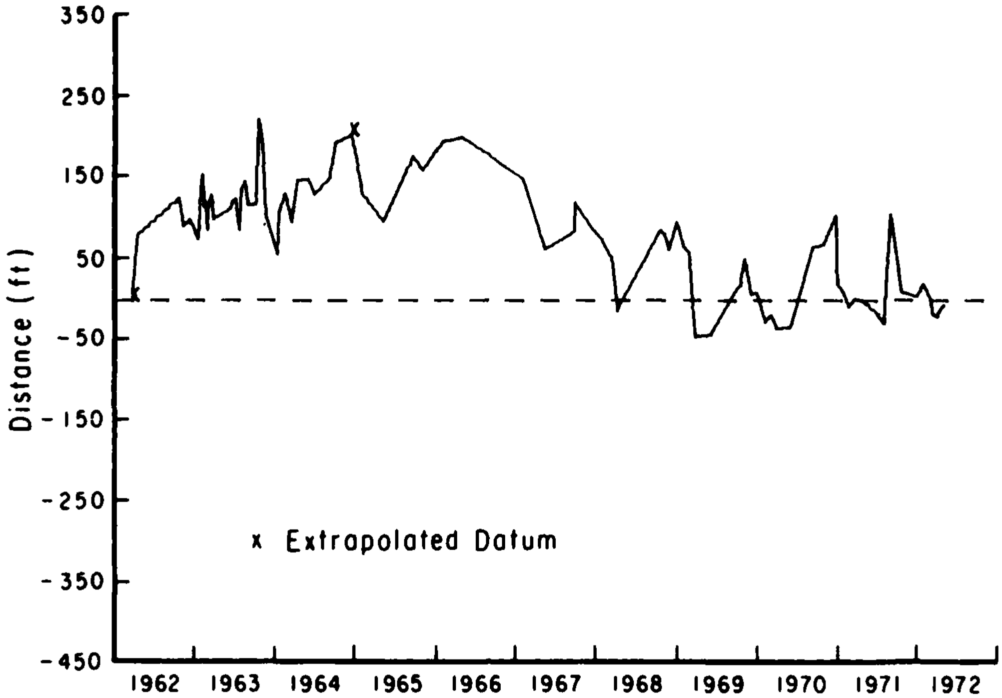

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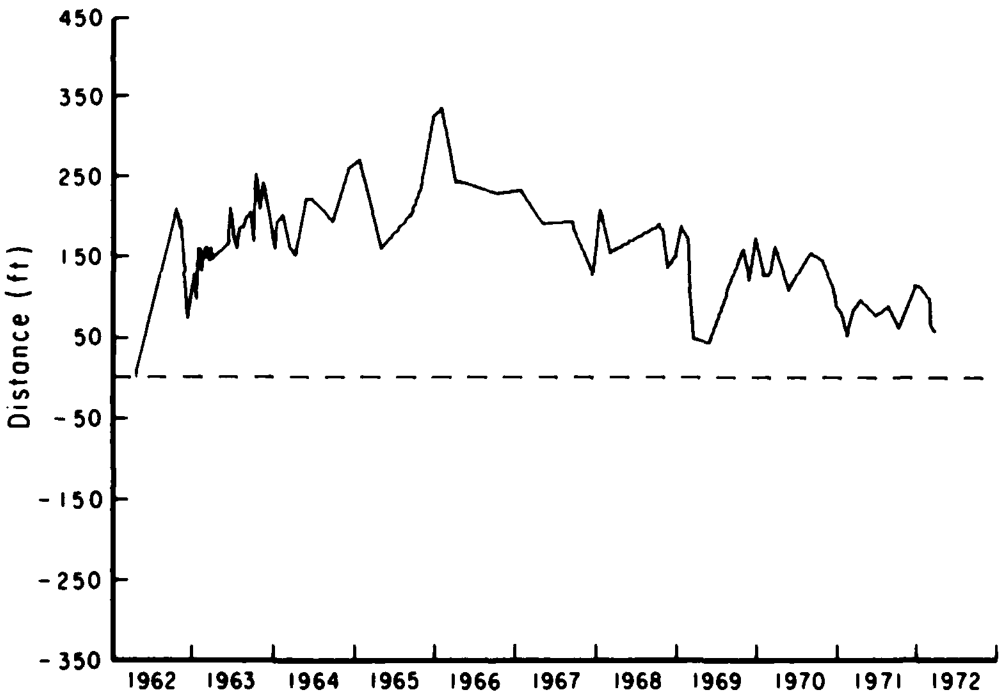

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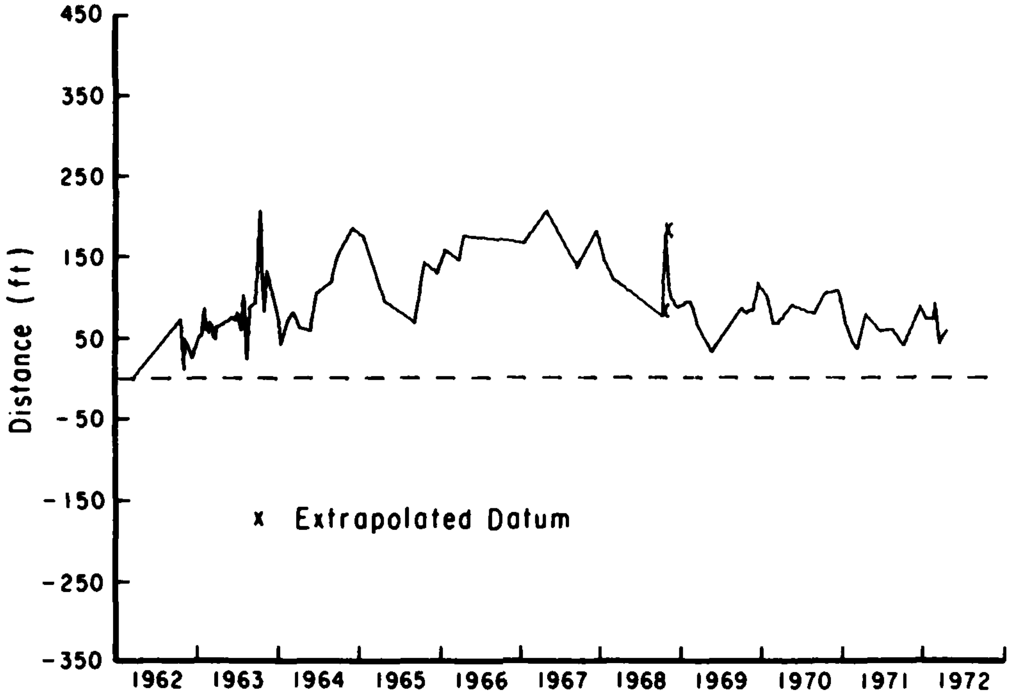

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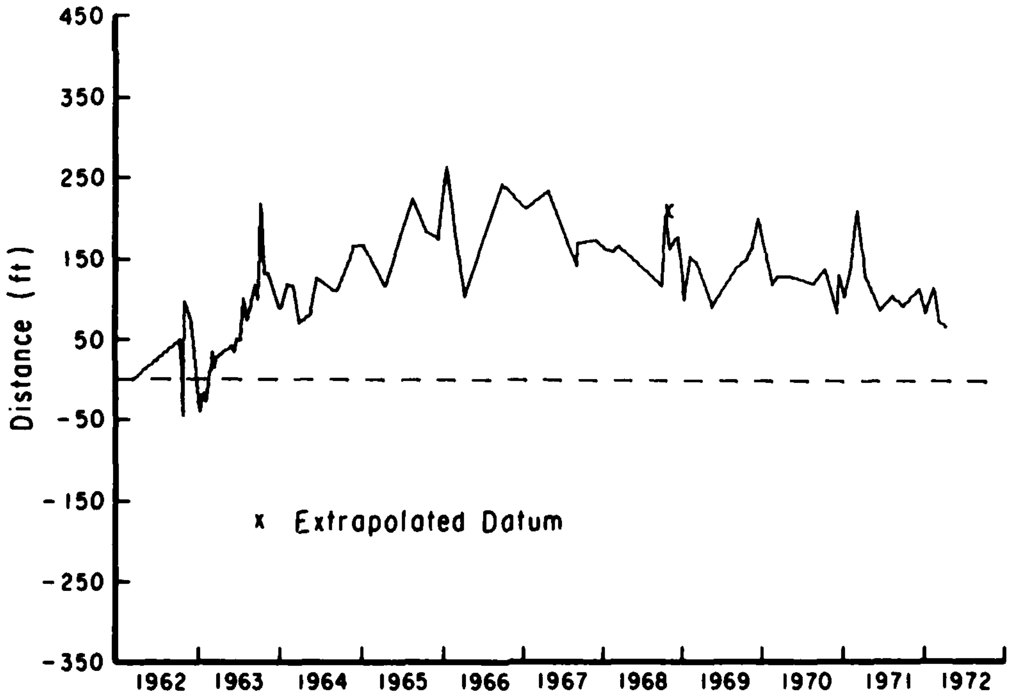

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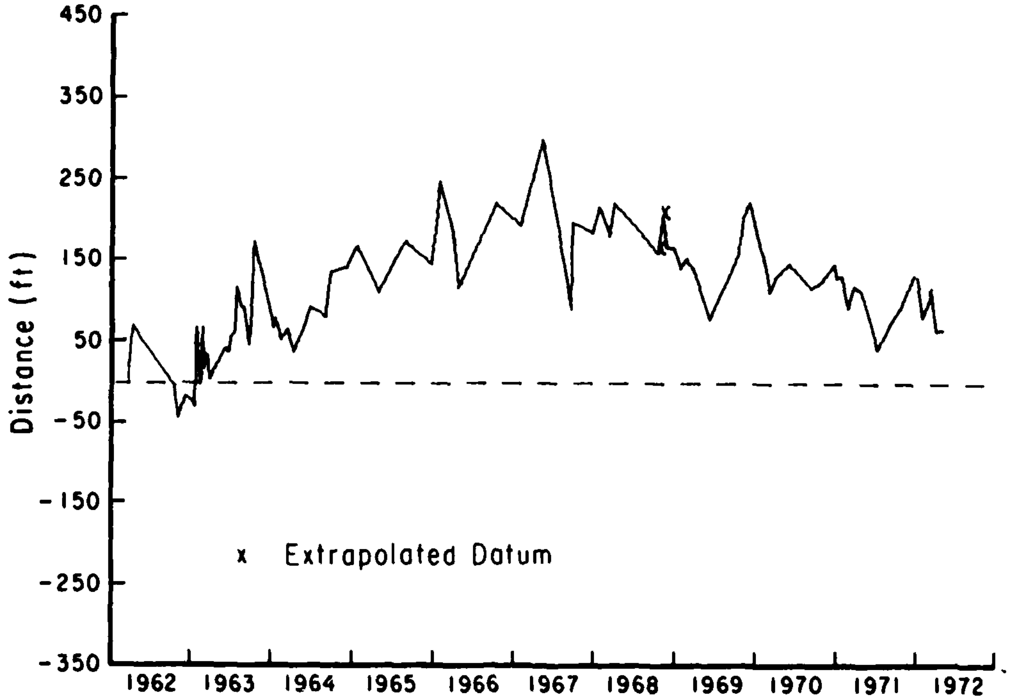

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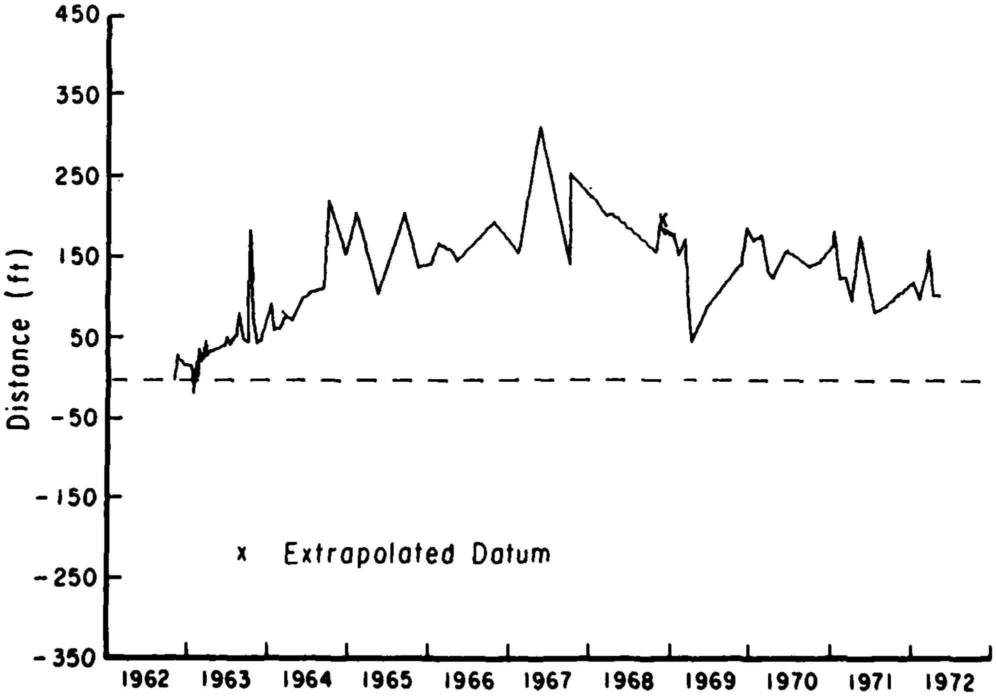

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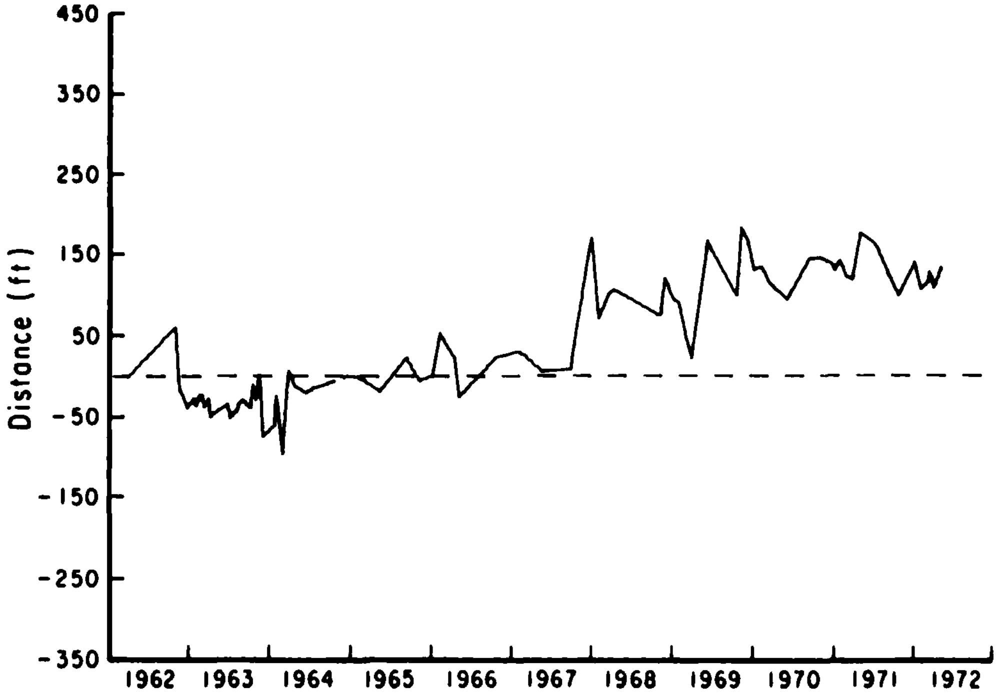

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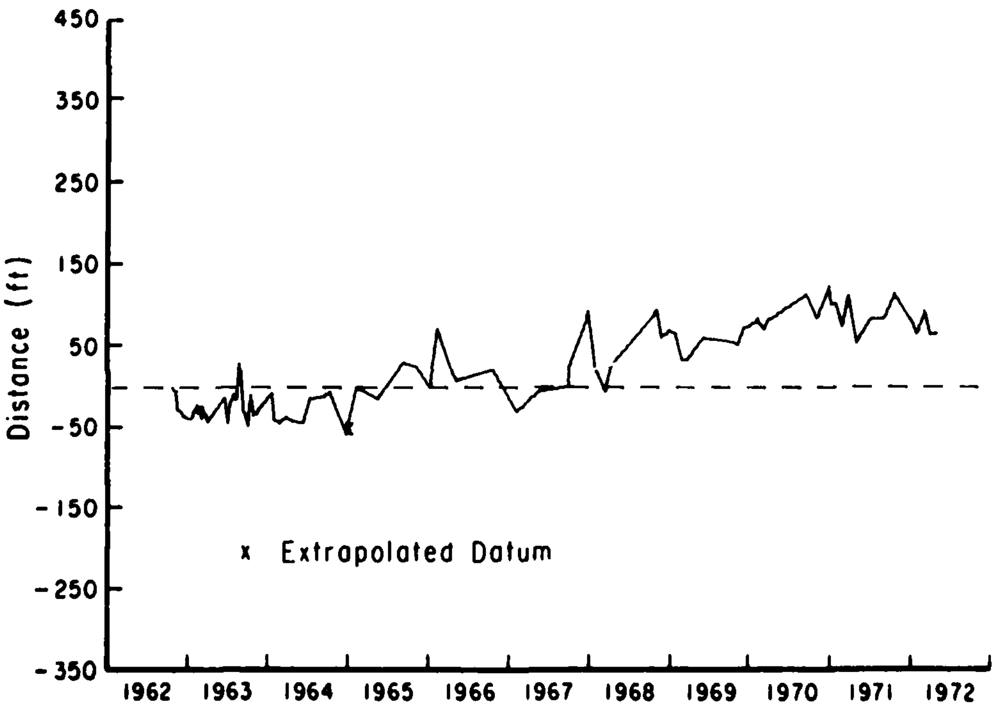

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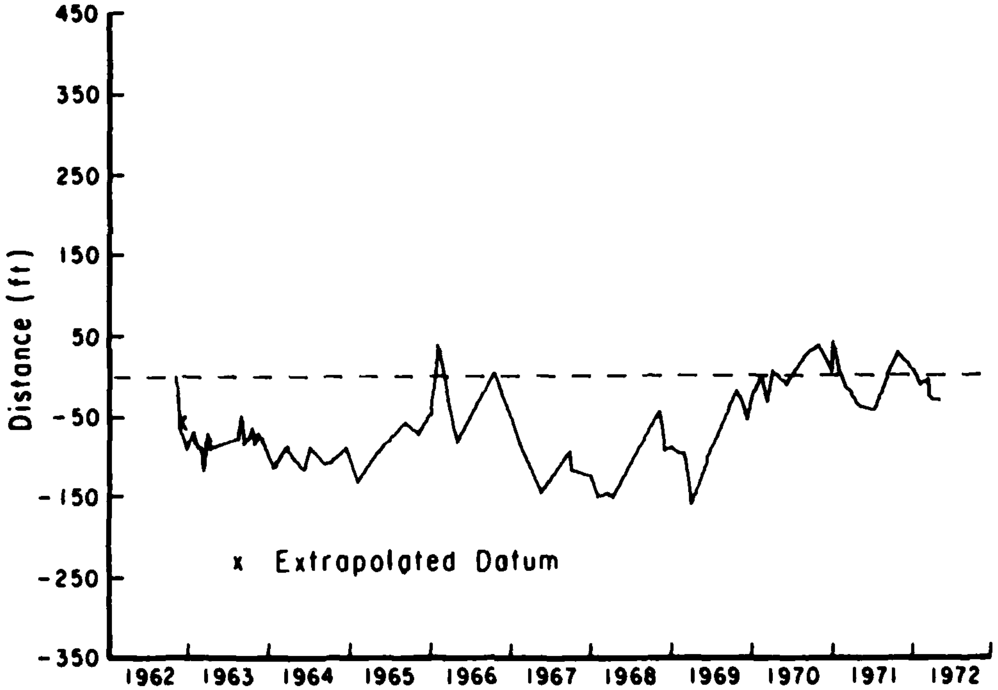

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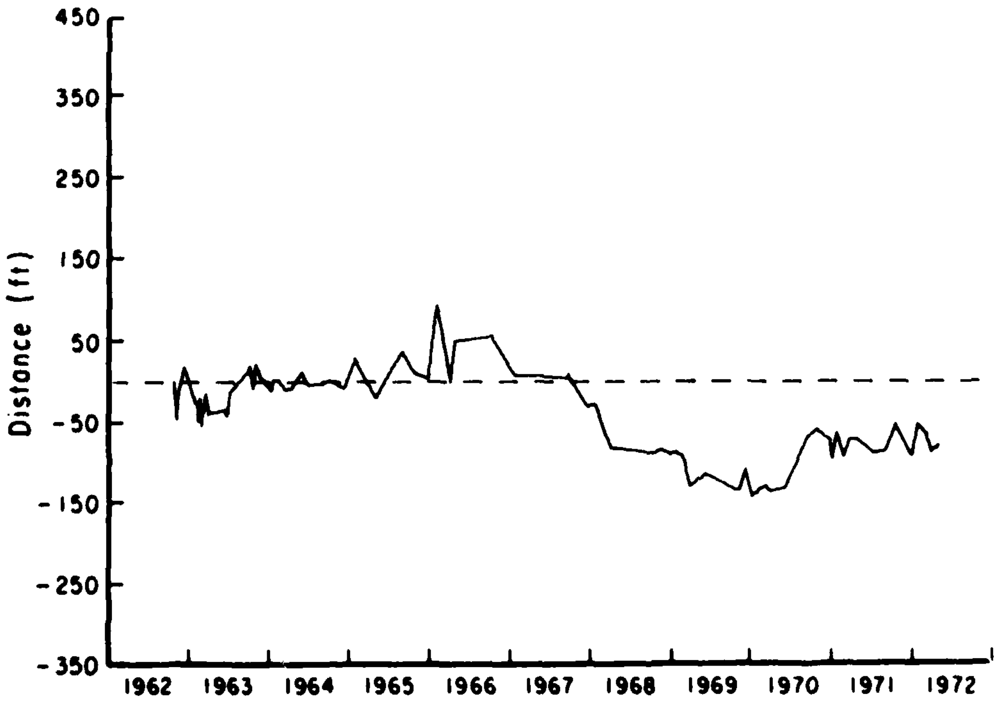

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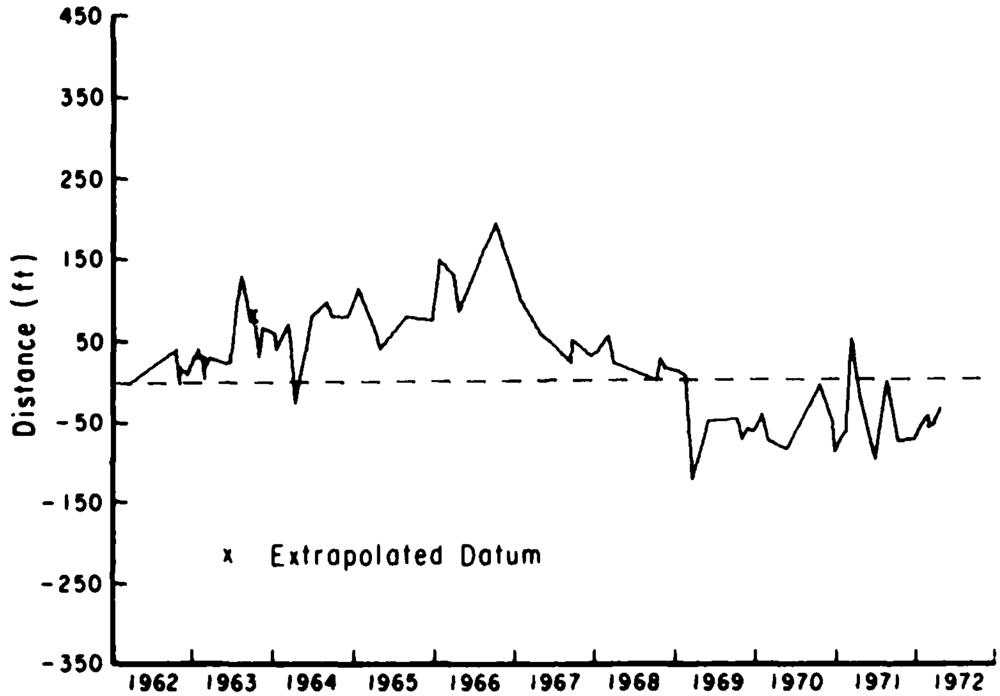

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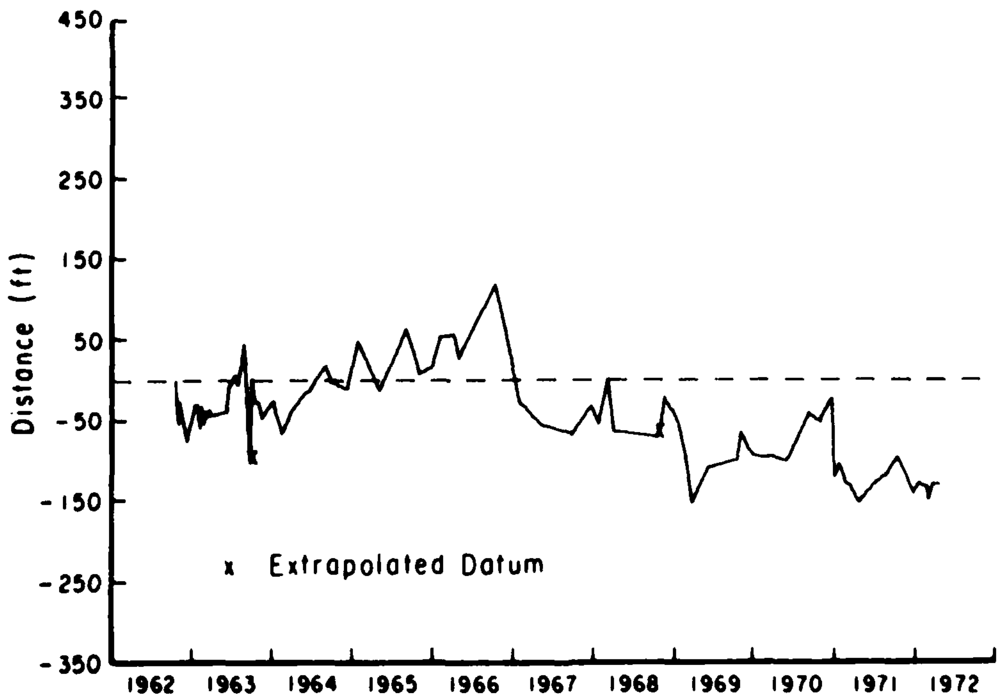

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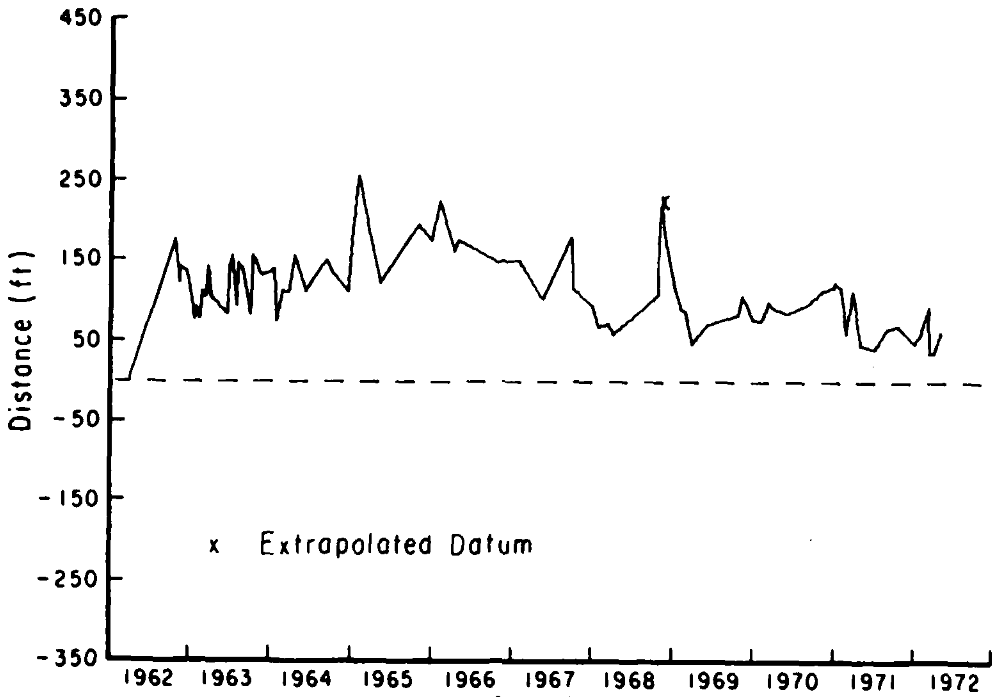

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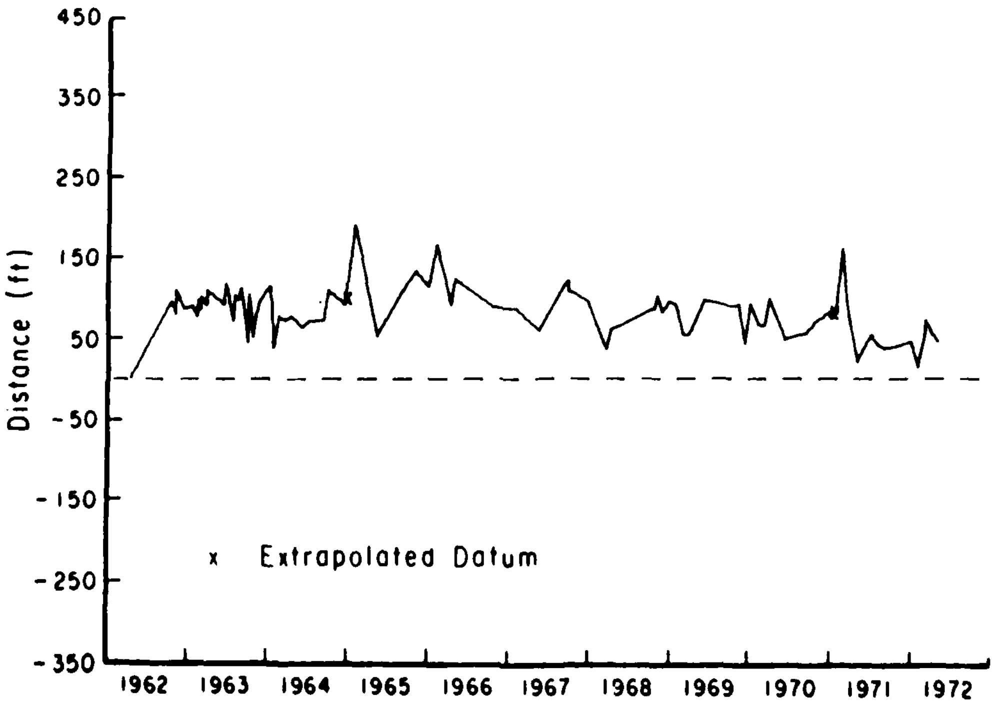

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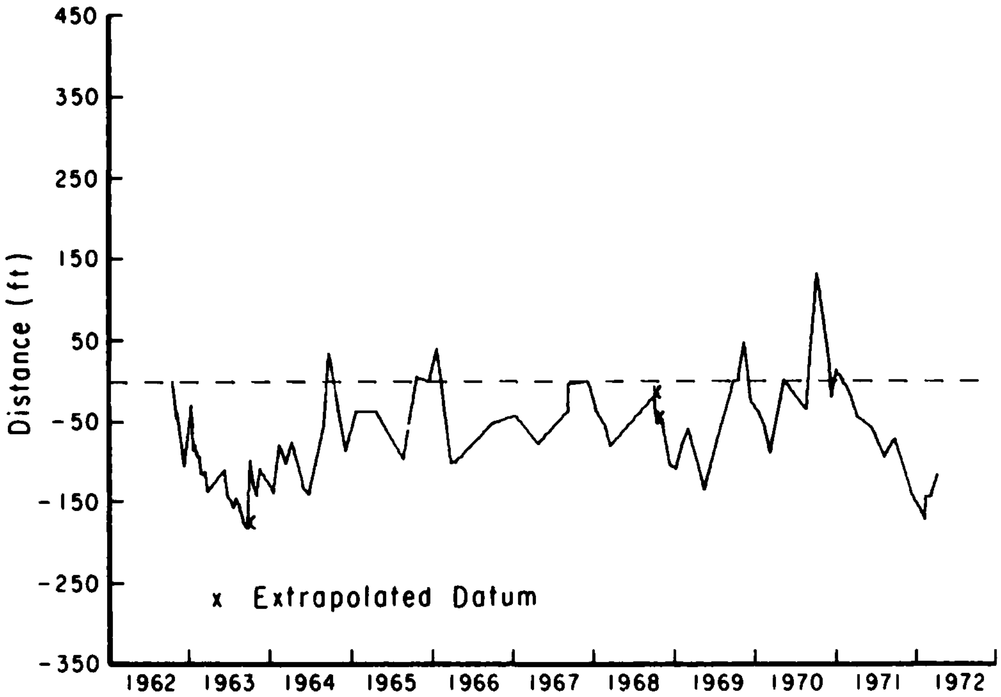

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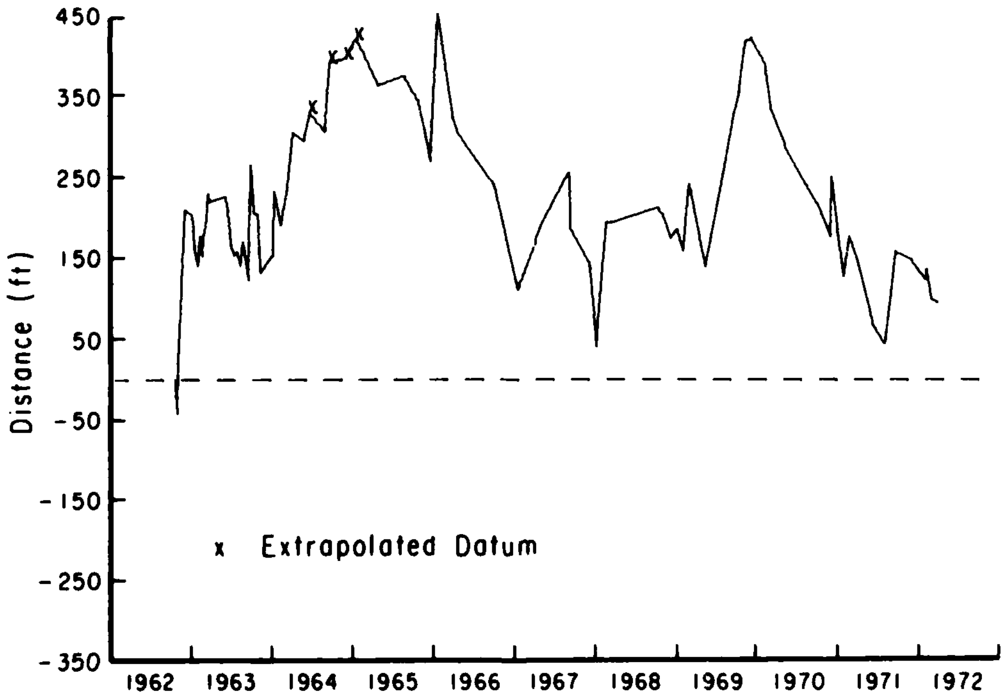
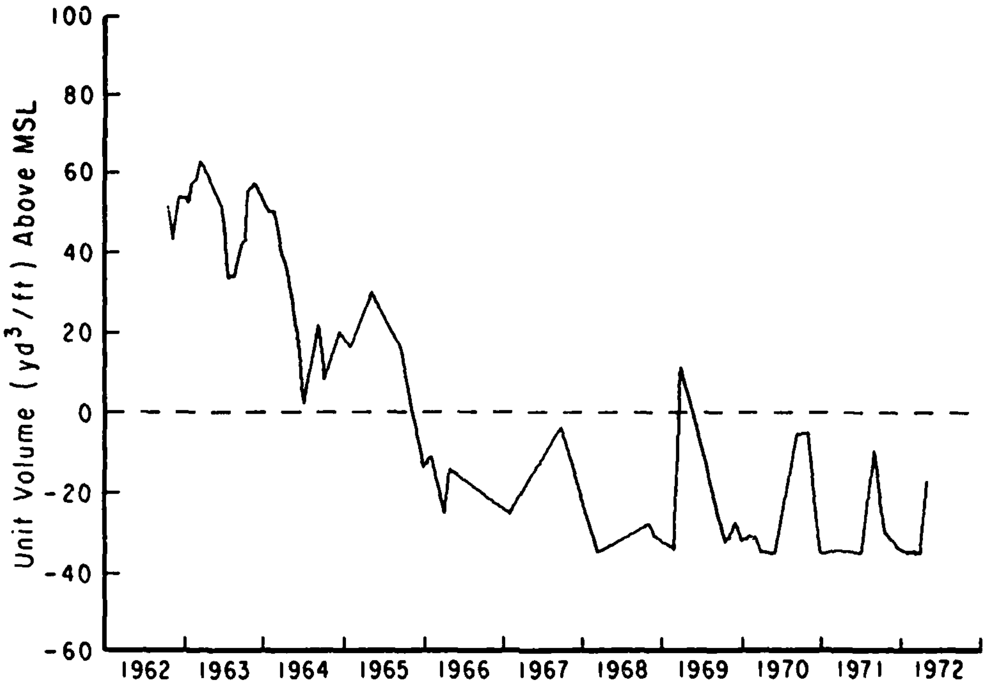


Profile Line 20

APPENDIX D

SAND VOLUME CHANGES ABOVE MSL, OCTOBER 1962 TO JULY 1972

This appendix presents changes in the volume of sand above MSL (in cubic yards per foot) on Ludlam Beach. Volume changes are referenced to the mean volume on each profile. Profile line locations are given in Appendix B.



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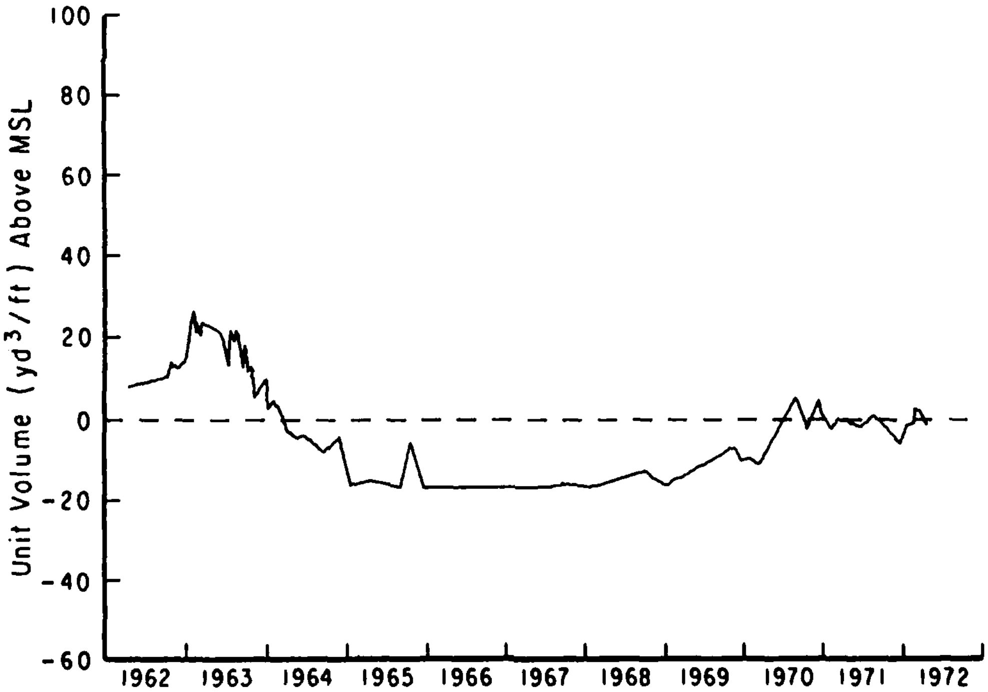

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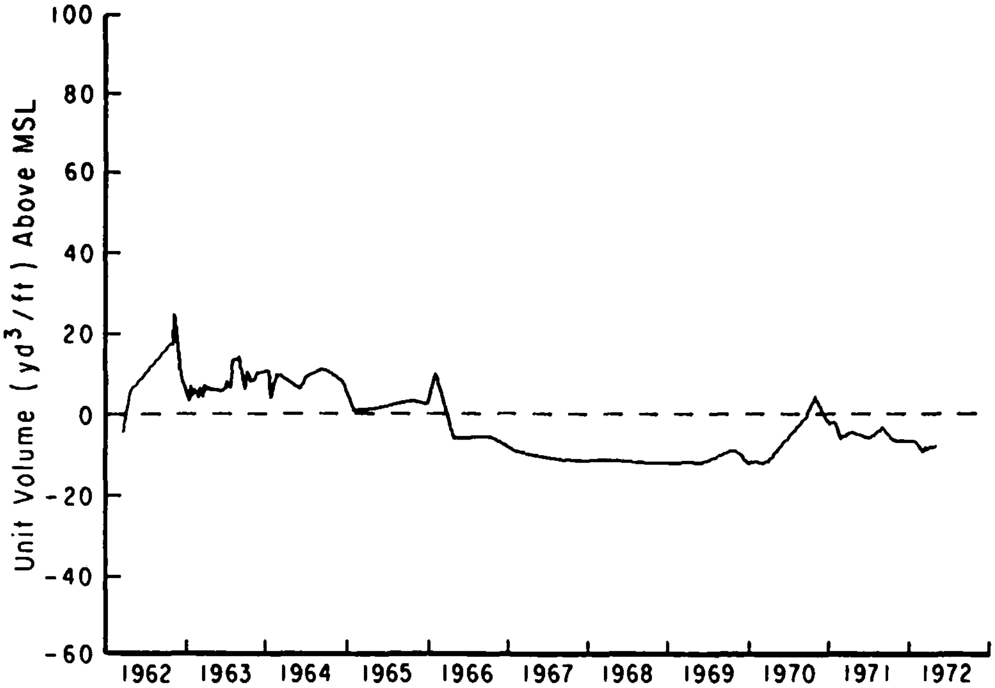

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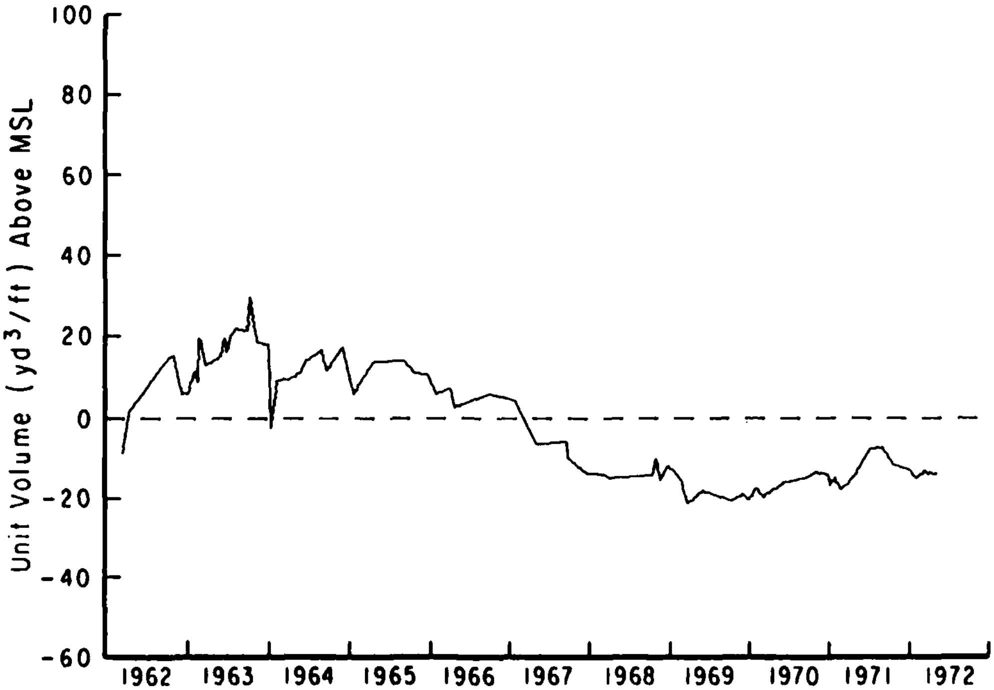

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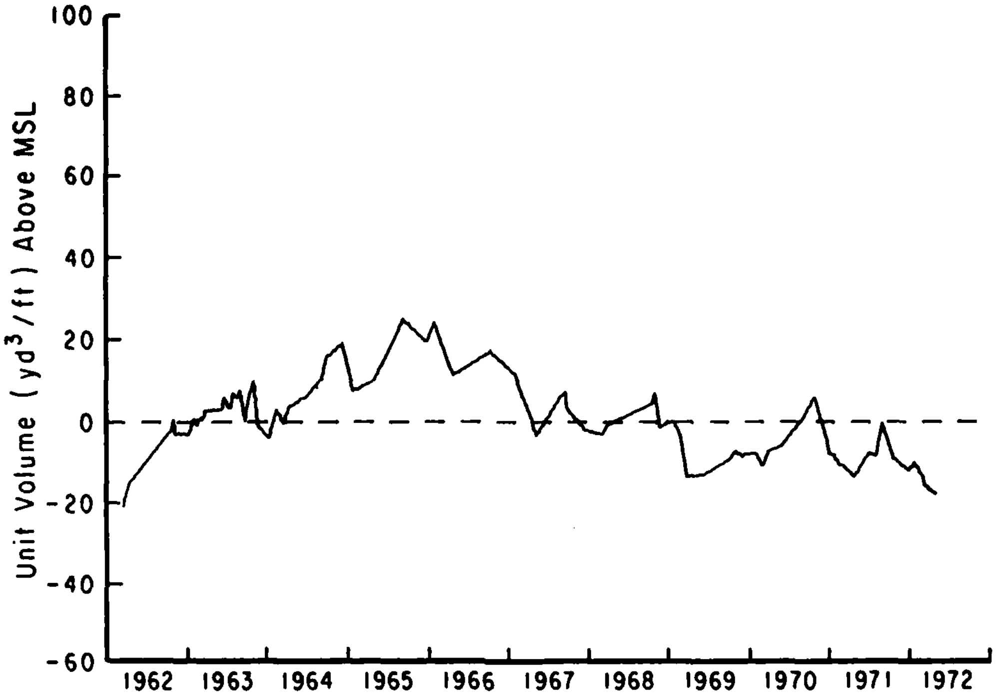

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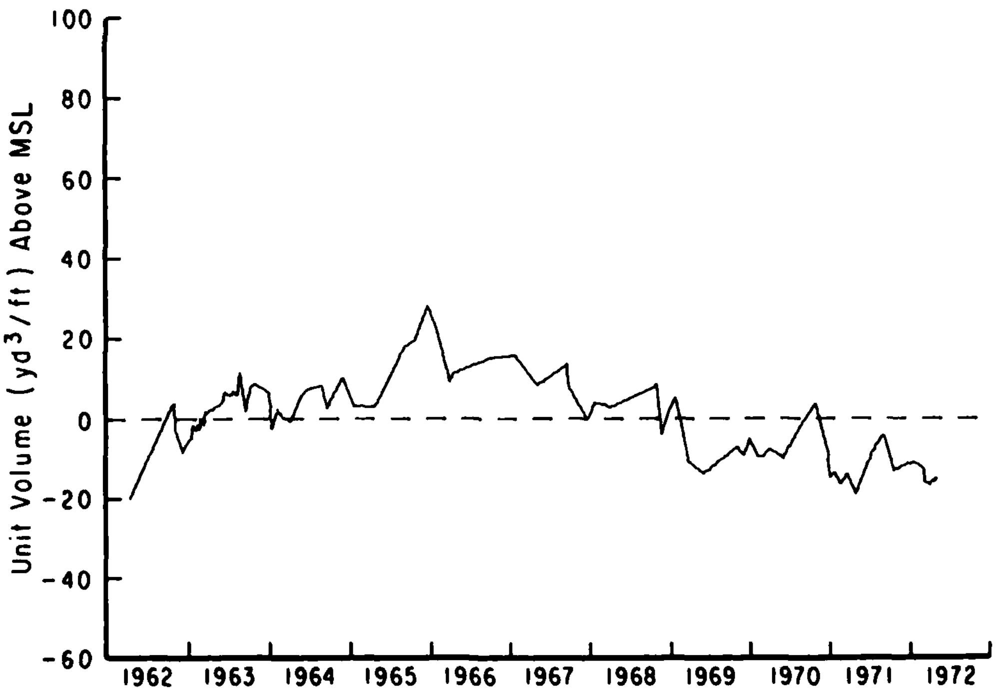

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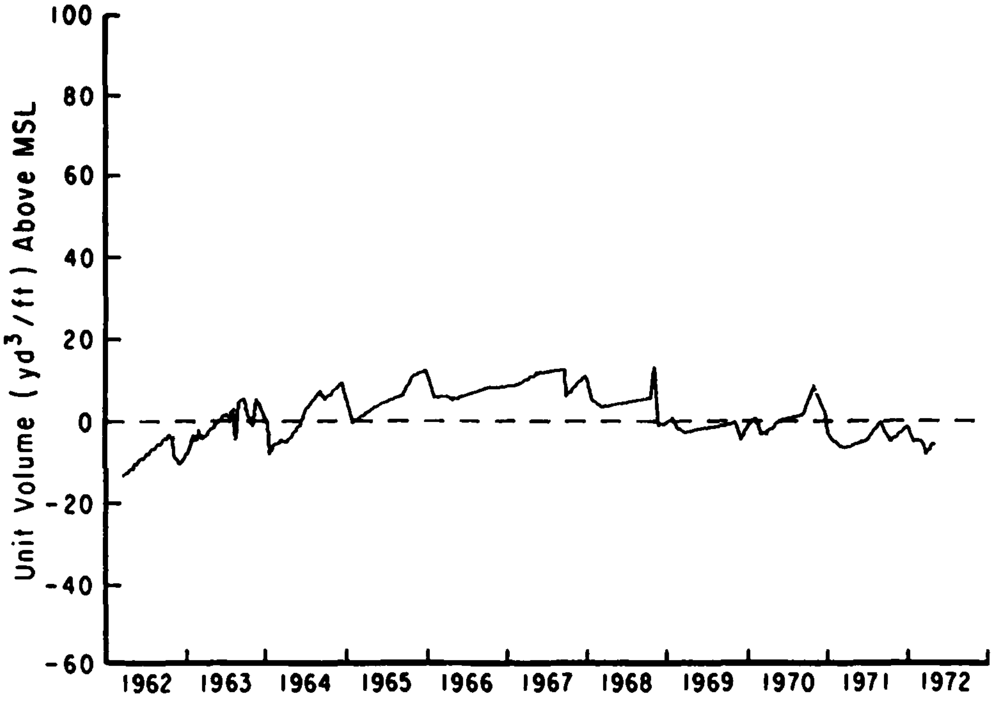

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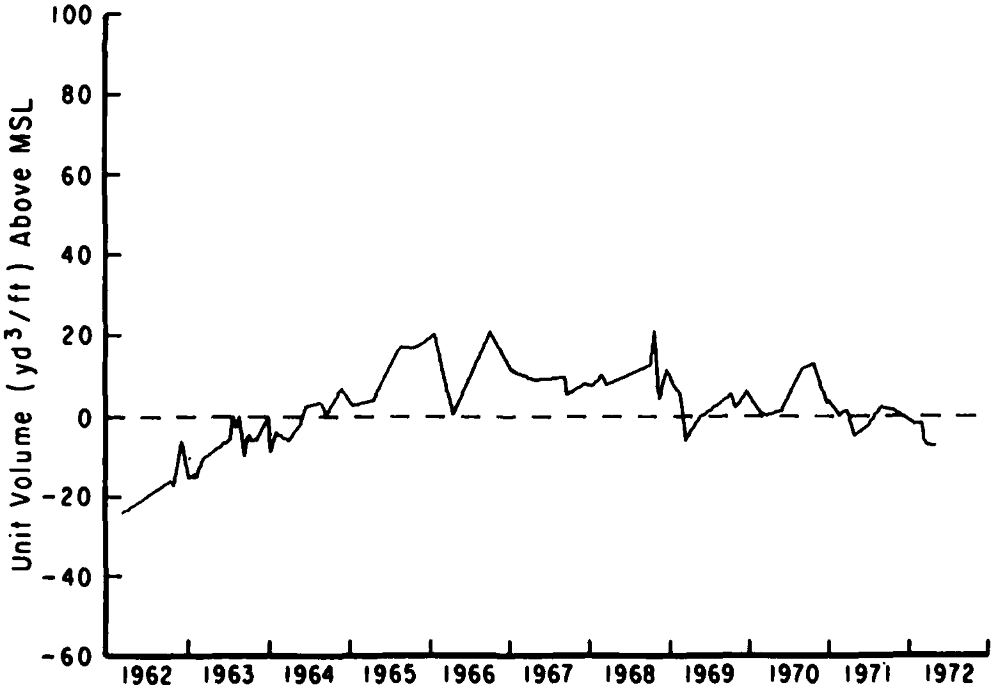

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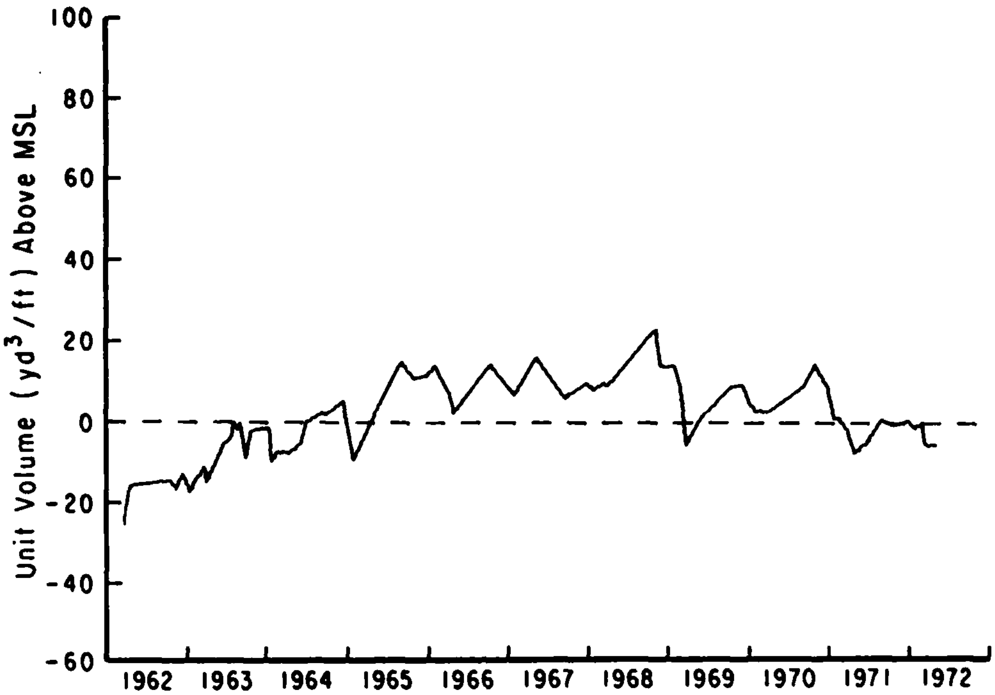

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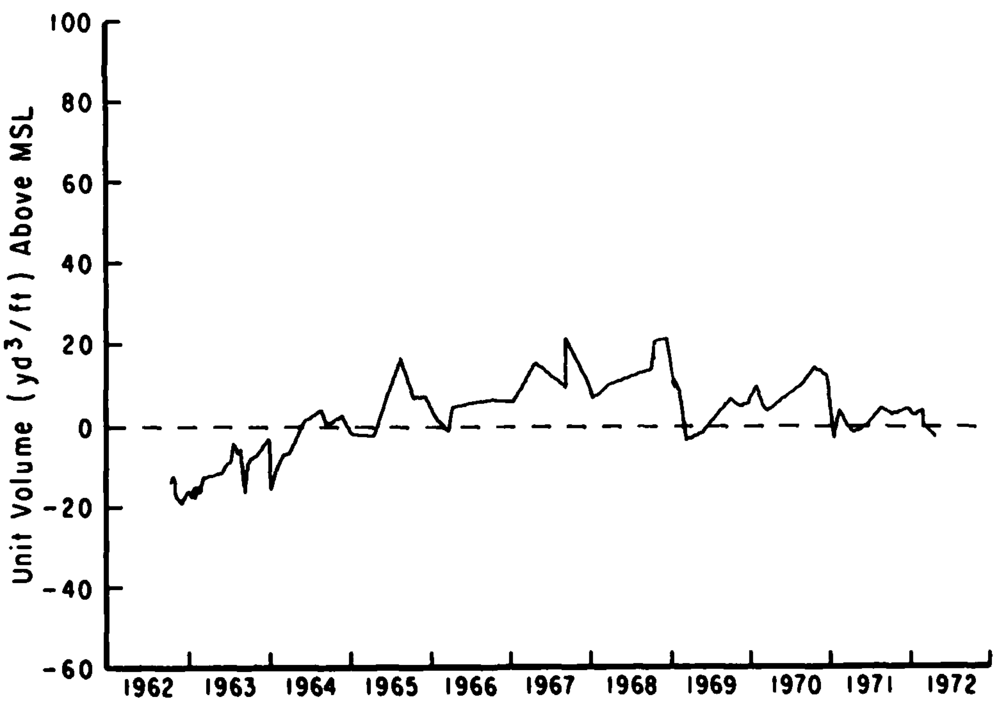

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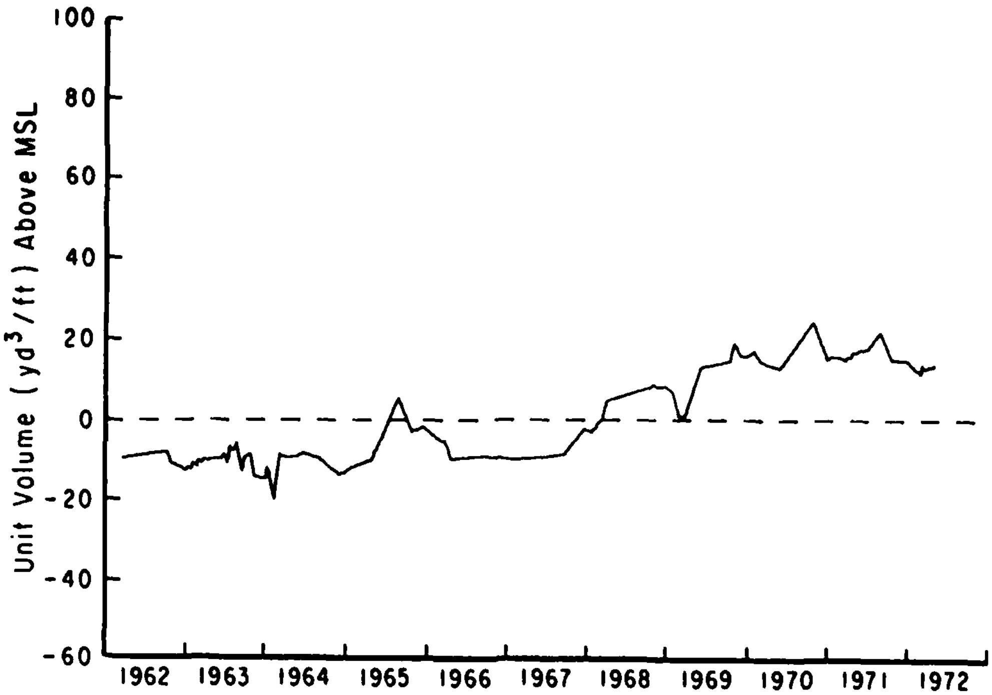

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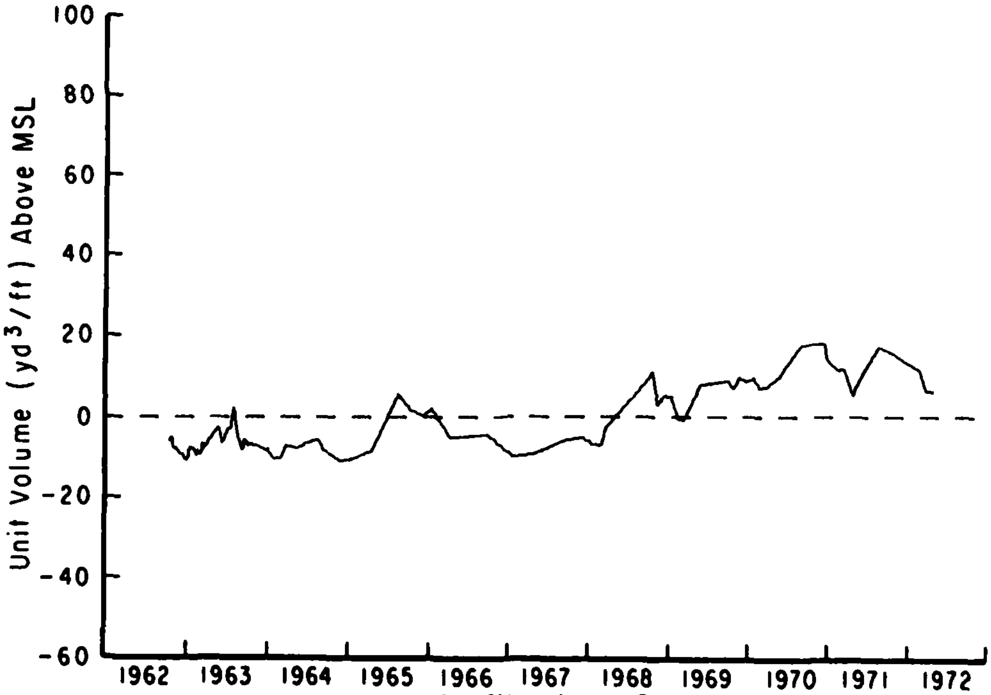

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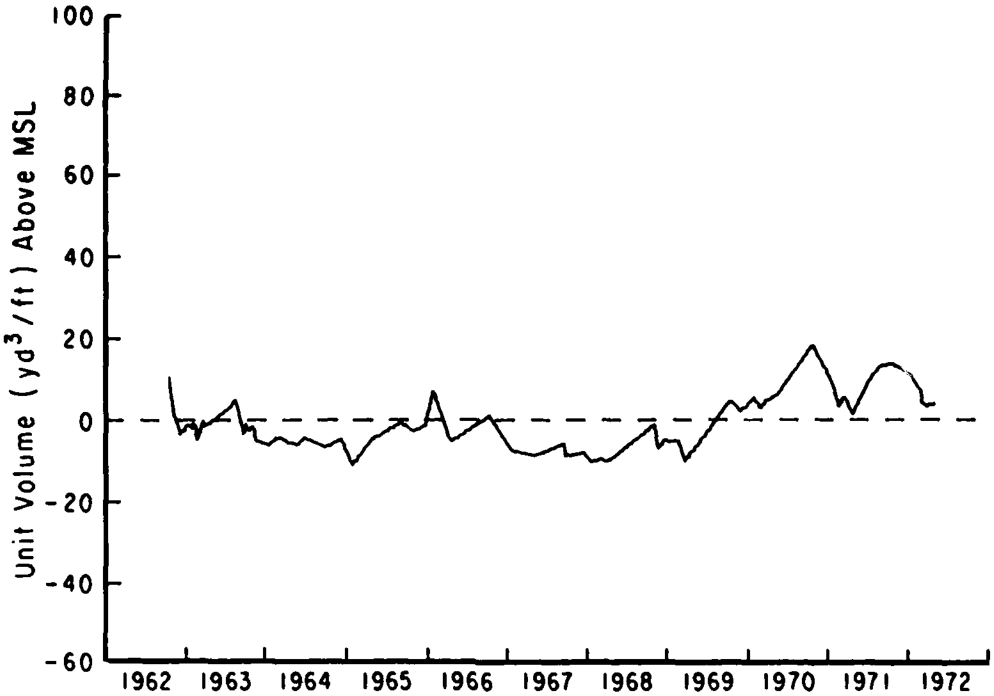

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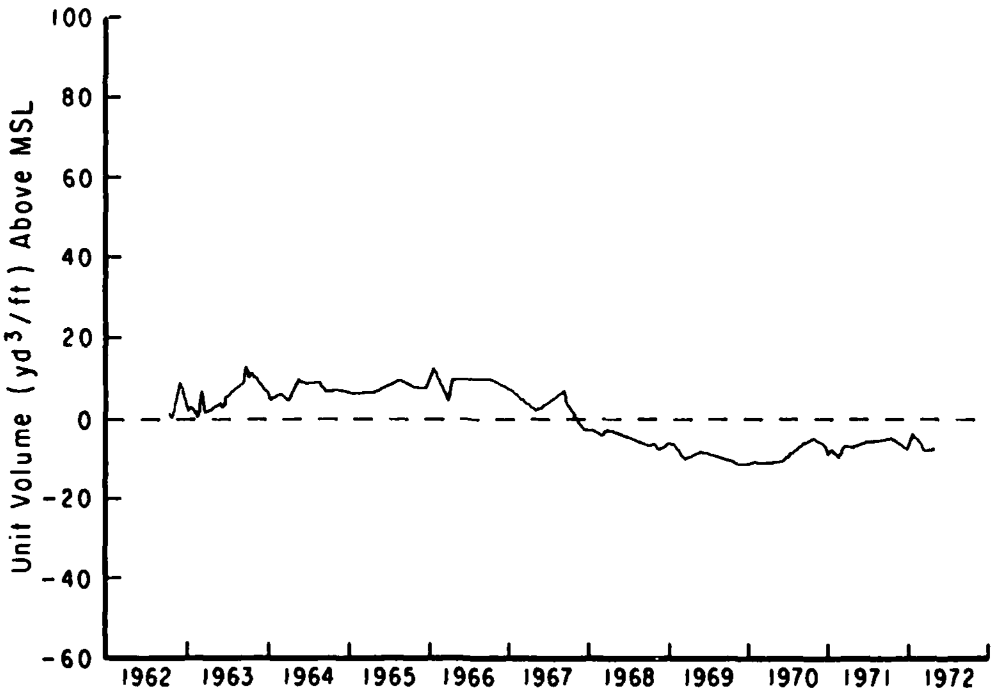

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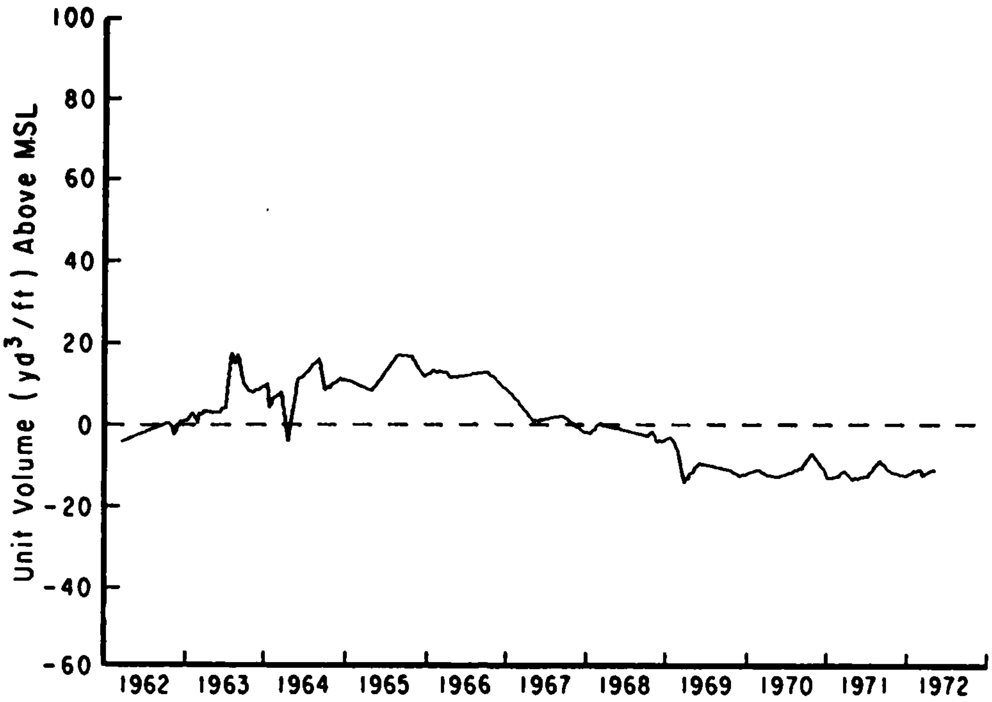

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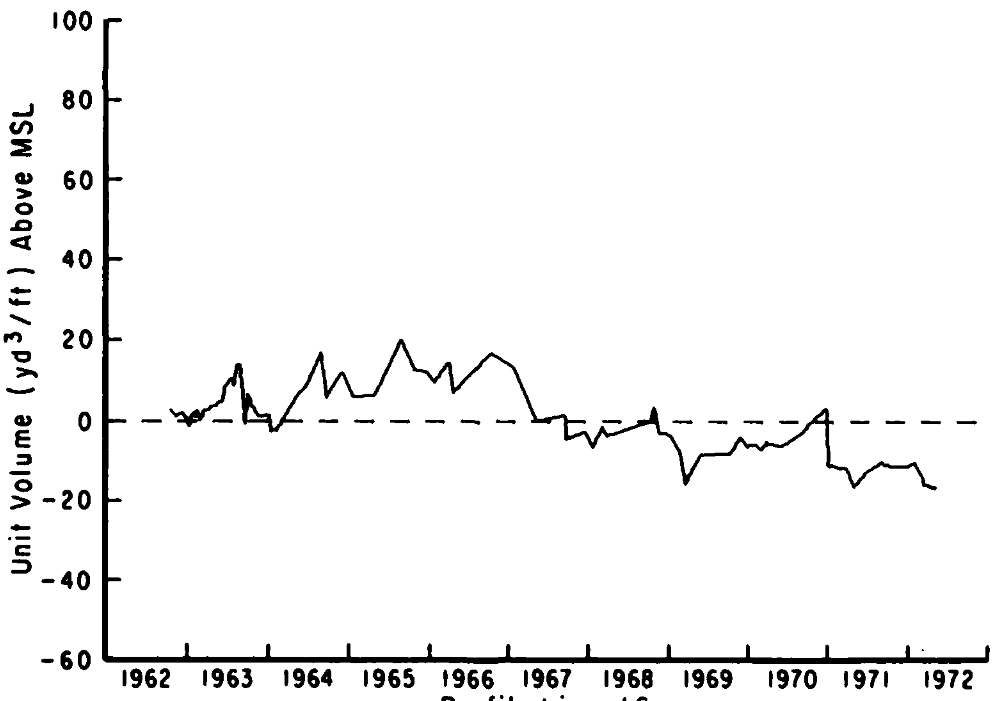

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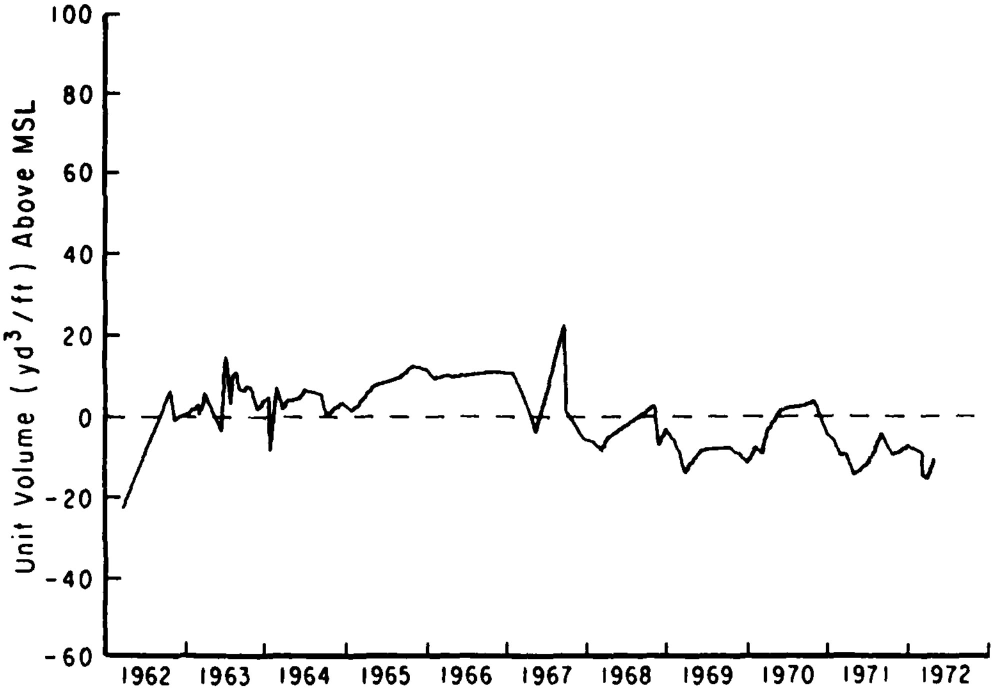

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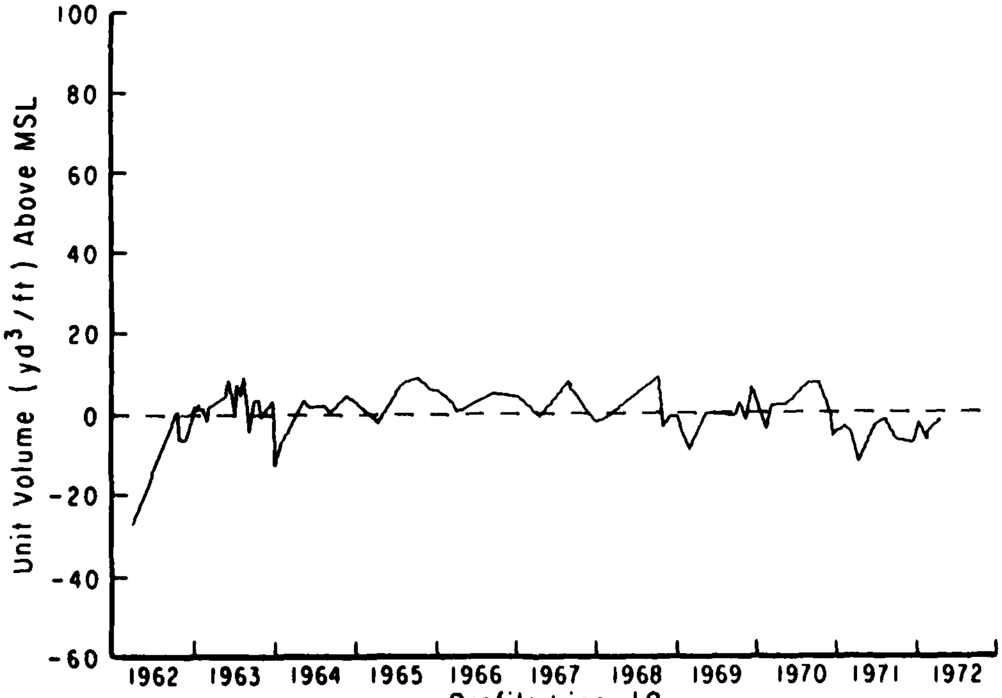

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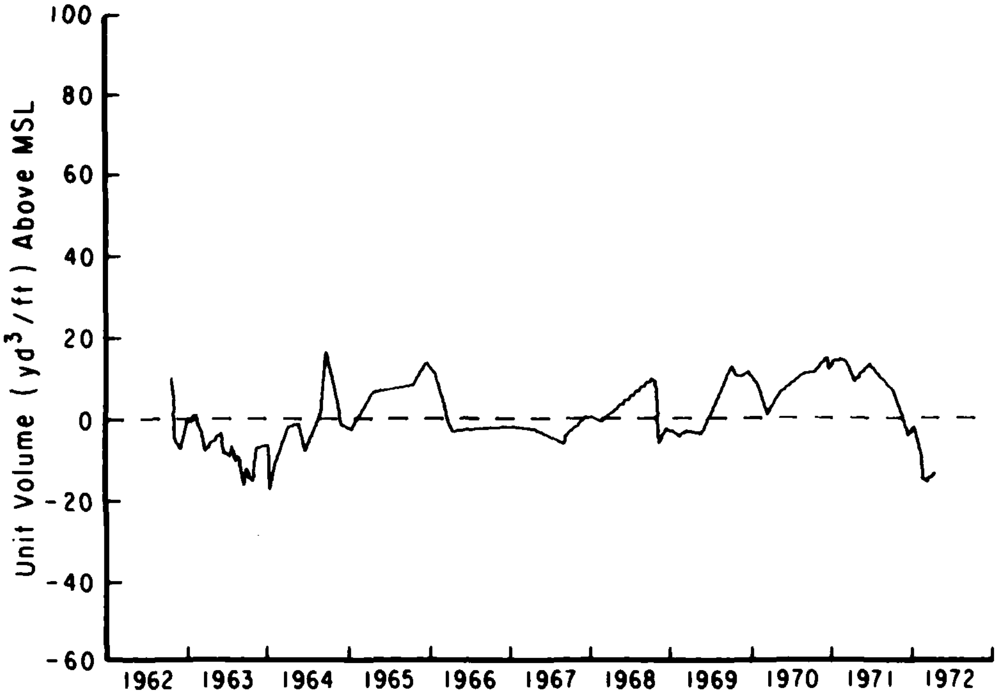

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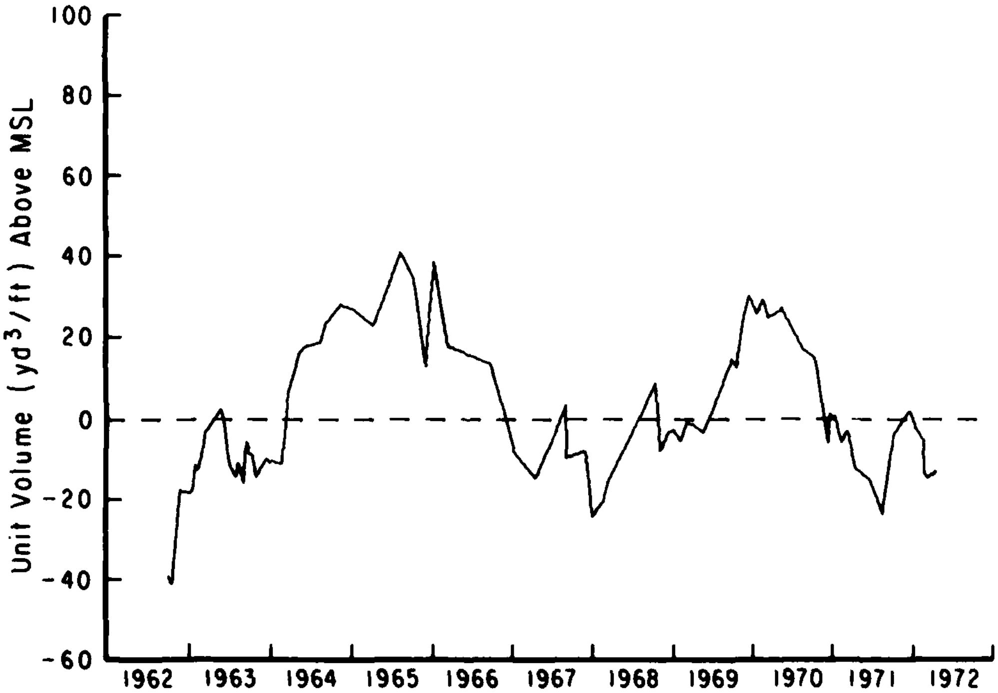

Profile Line 20

Everts, Craig H.
Beach and inlet changes at Ludlam Beach, New Jersey / by Craig H. Everts, Allan E. DeWall...[et al.].--Fort Belvoir, Va. : U.S. Coastal Engineering Research Center ; Springfield, Va. : available from National Technical Information Service, 1980.
[146] p. : ill : 27 cm.--(Miscellaneous report--U.S. Coastal Engineering Research Center ; no. 80-3).
Includes bibliographical references.
Appendixes.
Repetitive surveys of the above MSL beach were made along 20 profile locations on Ludlam Beach, New Jersey, from 1962 to 1972. The surveys provided data on temporal and spatial beach volume change and shoreline position.
1. Beach changes. 2. Beach erosion control. 3. Beach profile. 4. Groins. 5. Inlet changes. 6. Ludlam Beach, New Jersey. I. Title. II. DeWall, Allan E. III. Series: U.S. Coastal Engineering Research Center. Miscellaneous report no. 80-3.

TC203 .U581mr no. 80-3 627

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